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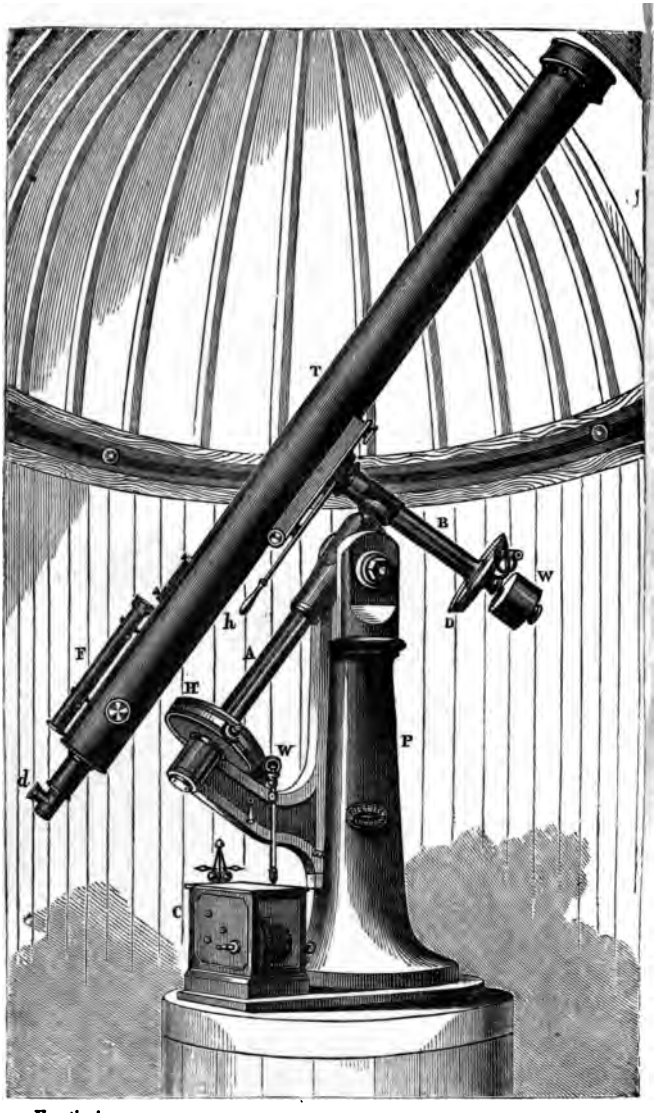

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TELESCOPE, MOUNTED EQUATORIALLY. (See p. 154.)

MATHEMATICAL INSTRUMENTS

THEIR CONSTRUCTION, ADJUSTMENT, TESTING, AND USE

Enlarged Edition, for the most part entirely re-written

VOL. III.

SURVEYING AND ASTRONOMICAL INSTRUMENTS

INCLUDING

I.—INSTRUMENTS USED FOR DETERMINING THE GEOMETRICAL FEATURES OF A PORTION OF GROUND

II.—INSTRUMENTS EMPLOYED IN ASTRONOMICAL OBSERVATIONS

BY

J. F. HEATHER, M.A.

LATE OF THE ROYAL MILITARY ACADEMY, WOOLWICH; AUTHOR OF "PRACTICAL PLANE GEOMETRY," "DESCRIPTIVE GEOMETRY," ETC., ETC.

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PREFACE TO VOL. III.

The original one-volume edition of the Treatise on Mathematical Instruments having now been expanded into three volumes, this third volume is devoted entirely to the consideration of Surveying Instruments and of Astronomical Instruments, forming Parts IV. and V. of the work.

The additional space thus obtained has been employed by the Author, in the first place, in describing more fully the several varieties of the instruments treated of, and in giving more detailed and comprehensive illustrations of their application; and, in the second place, in introducing entirely new chapters upon instruments for the determination of distances by observation, and upon the measurement of altitudes by the barometer and thermometer. A chapter has also been added to Part V. upon the construction and use of the Equatorial, undoubtedly the form of instrument best adapted for the examination of those phenomena of the solar orb, which now demand so much attention from the scientific world.

The Author is again bound to mention his obligations to Messrs. Elliott, who have kindly supplied several of the woodcuts that illustrate the volume, and to Messrs. Parkes and Son of Birmingham, who sent him a large number of instruments for inspection, among which were the Drawing and Mining Levels, described at pp. 37, 38.

To these gentlemen, and to all from whom he has derived assistance in the preparation of this and the preceding volumes, the Author begs leave again to return his most sincere thanks, and ventures to repeat the hope already expressed in the preface to the first volume, "that the skill of the workman may not appear to have been altogether inadequate to the manipulation of the materials supplied him."

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CONTENTS OF VOL. III.

PART IV.

SURVEYING INSTRUMENTS.

CHAPTER I.

INSTRUMENTS FOR MEASURING HORIZONTAL DISTANCES.

	PAGE
The Land Chain	2
Clinometers	7
The Offsetting Staff	8
Measuring Tape	9
Station Poles and Ranging Rods	9

CHAPTER II.

INSTRUMENTS FOR MEASURING VERTICAL DISTANCES.

The Spirit Level	10
The Y Level	12
Gravatt's Dumpy Level	20
Elliott's Improved Dumpy Level	22
The Improved Dumpy Y Level	24
Levelling Staves	24
Levelling, Remarks on	26
Water Level	33
Reflecting Level	34
Improved Reflecting Level	35
Draining and *Mining* Levels	36

CHAPTER III.

INSTRUMENTS FOR MEASURING ANGLES.

PAGE
The Prismatic Compass 39
The Box Sextant 47
Artificial Horizon 52
The Optical Square 53
The Cross Staff 53
The Line Ranger 54
The Theodolite 55
The Transit Theodolite 60
Everest's Theodolite 64
Lister's Patent Theodolite 66
The Theodolite of M. d'Abbadie 66
Measuring Angles with the Theodolite 67
Ranging Lines with the Theodolite 70
Traversing with the Theodolite 71
Plotting the Survey 74
Protracting by Chords 75
Northings, Southings, Eastings, and Westings 75

CHAPTER IV.

INSTRUMENTS FOR DETERMINING DISTANCES OF OBSERVED OBJECTS.

The Stadium 79
Edgeworth's Stadiometer 84
The Omnimeter 88

CHAPTER V.

INSTRUMENTS FOR THE DETERMINATION OF CONSIDERABLE HEIGHTS.

Preliminary Remarks on Hypsometrical Instruments . . . 92
The Mercurial Thermometer 96
The Standard Barometer 98
The Syphon Barometer 99
The Portable or Mountain Barometer 99
The Wheel Barometer 103
The Aneroid Barometer 104
Application of the Barometer to the determination of differences of Altitude 108
Meteorological Phenomena denoted by the Barometer . . . 118
Thermometric Hypsometry 124

PART V.

ASTRONOMICAL INSTRUMENTS.

CHAPTER I.

HADLEY SEXTANT.

PAGE
Description of the Sextant 127
Adjustment of the Sextant 130

CHAPTER II.

THE TRANSIT INSTRUMENT.

Description of the Transit Instrument 132
Adjustments of the Transit Instrument 135
Method of observing with the Transit 139
Use of the Portable Transit 141

CHAPTER III.

THE ALTITUDE AND AZIMUTH INSTRUMENT.

Description of the Altitude and Azimuth Instrument . . 142
Adjustments of this Instrument 144
Method of observing with this Instrument 146
Use of the Instrument 147

CHAPTER IV.

SUBSIDIARY INSTRUMENTS.

The Reading Microscope 149
The Collimator 151

CHAPTER V.

THE EQUATORIAL.

Description of the Equatorial 153
Adjustments of the Equatorial 154
Uses of the Equatorial 158
Mode of observing with the Equatorial 158

MATHEMATICAL INSTRUMENTS.

PART IV.

SURVEYING INSTRUMENTS.

SURVEYING consists in the measurement of such distances and angles, as shall most correctly, and conveniently, define the boundaries of a plot of ground, as well as the positions of the various objects that diversify its surface, whether natural, as hills, rivers, forests, &c., or artificial, as roads, railways, canals, &c.

From the measurement thus made, these boundaries and objects can be laid down on paper, so as to preserve their *relative* magnitudes and positions, the observed measurements being all reduced in the same proportion. The features of the ground thus laid down, form what is called a map or plan, according as the plot of ground represented is of greater or smaller extent; and the process of laying it down is called *plotting the survey*.

The instruments used in plotting, and also in the copying, reduction, and measurement, of maps and plans, are fully described in the volumes on Mathematical Drawing, Measuring, and Optical Instruments. It remains, then, to describe:—(1) The instruments used for measuring horizontal distances; (2) the instruments used for measuring vertical distances; and (3) the instruments used for measuring angles.

CHAPTER I.

INSTRUMENTS FOR MEASURING HORIZONTAL DISTANCES

THE LAND CHAIN.

GUNTER'S chain is the instrument used almost universally for measuring the distances required in a survey. For extensive and important surveys, however, such as those carried on under the Board of Ordnance, a base of about 5 or 6 miles in length is first measured by some more accurate instrument, and all the principal lines, and the distances of the extreme points, are calculated from triangles connecting them with this base. One of the instruments which has been used for this purpose was a steel chain 100 feet long, constructed by Ramsden, jointed like a watch chain. This chain was always stretched to the same tension, supported on troughs laid horizontally, and allowances were made for changes in its length made by temperature, at the rate of ·0075 of an inch for each degree of heat from 62° of Fahrenheit. More recently, compound rods have been used, so constructed that, by the unequal expansion of two metals, two points on cross-pieces, connecting the ends of the two bars composed of those metals, always remain at the same distance from each other.

To return, however, to Gunter's chain:—it is 66 feet, or four poles in length, and is divided into 100 links, which are joined together by rings. The length of each link, together with the rings connecting it with the next, is, consequently, $\frac{66 \times 12}{100}$ inches or 7·92 inches. To every tenth link are attached pieces of brass of different shapes for more readily counting the links in distances less than a chain. They are something like the fingers of the hand, one finger being placed at the tenth link, two fingers at the twentieth link, three at the thirtieth, and four at the fortieth; and at the fiftieth link, or centre of the chain, is placed a round mark. The same marks, in the reverse order, are placed beyond the centre; so that one finger may denote either ten links, or ninety links; two fingers, either twenty, or eighty links, &c.,

accordingly as they lie before, or beyond, the centre. At each end of the chain is a brass handle, by which to hold and pull it straight when in use.

The following tables exhibit the number of chains and links in the different units of lineal measure, and the number of square chains and links in the different units of square measure, made use of in this country :—

A TABLE OF LINEAR MEASURES

Links.	Feet.	Yards.	Poles.	Chains.	Furlongs.	Mile.
25	16½	5½	1			
100	66	22	4	1		
1,000	660	220	40	10	1	
8,000	5,280	1,760	320	80	8	1

A TABLE OF SQUARE MEASURES.

Sq. Links.	Sq. Feet.	Sq. Yards.	Sq. Pole, or Perch.	Sq. Ch.	Roods.	Acres.	Sq Mile.
625	272¼	30¼	1				
10,000	4,356	484	16	1			
25,000	10,890	1,210	40	2½	1		
100,000	43,560	4,840	160	10	4	1	
64,000,000	27,878,400	3,097,600	102,400	6,400	2,560	640	1

As, then, an acre contains 100,000 square links, if the content of a survey, cast up in square links, be divided by 100,000, the quotient gives at once the content in acres, and decimals of an acre. But the division by 100,000 is performed by merely pointing off the five last figures towards the right hand for the decimals of an acre, and the remaining figures towards the left hand are the acres in the content required.

The decimals thus pointed off being then multiplied by 4, and the five last figures pointed off as before, the remaining figures are the roods; and the five decimals cut off from this product, multiplied by 40, give the poles or perches, and decimals of a pole, the same number, 5, of digits being again pointed off, including the zero which arises

```
   1175
   1175
   ----
   5875
  8225
 12925
 -------
13·80625
      4
 -------
3·22500
     40
 -------
9·00000
```

from the multiplication by 40. Thus, if the side of a square field measured 11 chains, 75 links, or 1175 links, the area of the field would contain 1175 × 1175, or 1,380,625 square links, which is equivalent to 13·80625 acres. Then ·80625 acres is equivalent to ·80625 × 4, or 3·22500 roods; and, again, ·22500 roods is equivalent to ·22500 × 40, or 9·00000 poles. The field consequently would measure 13 acres, 3 roods, 9 poles.

Ten arrows must be provided with the chain, about 12 inches long, pointed at one end, so as to be easily pressed into the ground, and turned at the other end, so as to form a ring, to serve for a handle by which they may be hung on the finger.

In using the chain, marks are first to be set up at the extremities of the line to be measured. Two persons are then required to perform the measurement. The chain leader starts with the ten arrows in his left hand, and one end of the chain in his right, while the follower remains at the starting-point, and, looking at the mark or staff at the other extremity of the line to be measured, directs the leader to extend the chain in the direction of this mark. The leader then puts down one of his arrows, and proceeds a second chain's length towards the end of the line, while the follower comes up to the arrow first put down. A second arrow being now put down by the leader, the first is taken up by the follower, and the same operation is repeated till the leader has expended all his arrows. Ten chains, or 1000 links, have now been measured, and this measurement having been noted in the field book, the follower returns the ten arrows to the leader, and the same operations are repeated. When the leader arrives at the end of the line, the number of arrows in the follower's hand shows the number of chains measured since the last exchange of arrows noted in the field book, and the number of links extending from the last arrow to the mark, or staff, at the end of the line being also added, gives the entire measurement of the line. Thus, if the arrows have been exchanged 9 times, and if the follower have 4 arrows, and from the arrow last laid down to the end of the line measure 63 links, the whole measurement will be 9463 links.

$$\begin{array}{r} 9000 \\ 400 \\ 63 \\ \hline 9463 \end{array}$$

To assist, in preserving the line straight as well as to

serve for a check upon the number of chains measured, it is a good method to set up a staff at each ten chains, when the arrows are exchanged.

In using the chain care must be taken to stretch it always with the same tension. As it will give when much used, especially when new, it should constantly be examined, and shortened if necessary. For this purpose a chain's length should be accurately set out on a level piece of ground, or along the coping of a wall,* as a standard, and before taking the chains out for use, any links that may have got bent should first be straightened, and the chain then compared with the standard. The excess of length, if any, above the standard, should then be corrected by shortening equally two of the links, the first link, for instance, and the fifty-first, or first beyond the centre to begin with; on the next occasion, the twenty-fifth and the seventy-fifth; on the third, the forty-ninth and the hundredth; on the fourth, the eleventh and eighty-ninth; and on the fifth, the thirty-ninth and sixty-first. After this, the shortening, when necessary, may be proceeded with by taking in like order the links adjoining these. By this means the shortening is equally distributed throughout the chain; so that not only the entire length, but the lengths from any one point to the other, are kept as nearly as possible correct. The shortening should be made by the removal of a ring at the end of the link, when the elongation is sufficient to require it.

When the ground over which the measurement is taken rises or falls, or both alternately, the horizontal distances are what we require for plotting the survey, and not the actual distances measured along the line of the ground.

For many ordinary purposes the horizontal measurement may be obtained by holding one end of the chain up, so as to keep it, as nearly as can be judged, horizontal, the arrow being placed vertically under the end so held up; and, to ensure this, both leader and follower should be provided with a line and weight at the end, to be used as a plummet. When, however, the measured line is of considerable length, and

* When making a standard chain cable for the Government base line at the Cape of Good Hope, Messrs. Elliott Brothers laid down very correctly, on the parapet of Somerset House, a distance of 100 feet. There are brasses inserted into the granite at every 10 feet, on which are cut the divisions. This information may be very useful to surveyors, as there is no other standard length laid down in London.

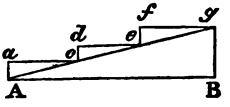
forms one of the principal lines of an extensive survey, the distances must be measured along the line of ground, and, the angles of elevation and depression of the several inclined parts of the line being afterwards taken with the theodolite (p. 55), or the vertical risings and fallings being taken by the process of levelling with the spirit level (p. 12) and staves (p. 25), the correct horizontal distances must thence be computed.

The following table shows the number of links to be subtracted from every chain, or 100 links, for the angles there set down, being in fact the versed sines of those angles to a radius of 100. The correction for each 100 links, for any angle whatever, may at once be taken from a table of natural versed sines, by considering the first two figures as integers. The correction may also be taken from a table of natural cosines, by subtracting each of the first four figures from 9, and reckoning the first two figures as integers, and the last two as decimals: thus, to find the correction for an inclination of 8° 19′, take the first four figures of the cosine of 8° 19′, which will be 9894, and subtracting each of these four figures from 9, we obtain 0105: then, considering the first two figures of this result as integers, and the last two as decimals, we have 1·05 for the correction, due to the inclination 8° 19′, for every 100 links. If the last figure in the correction thus found be increased by 1, whenever the fifth figure of the cosine is less than 5, the result will be more accurate.

TABLE showing the Reduction, in Links and Decimals of a Link, upon 100 Links, for every Half Degree of Inclination from 3° to 20° 30′.

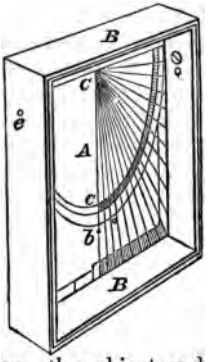
Angle.	Reduction.	Angle.	Reduction.	Angle.	Reduction.
3° 0′	0·14	9° 0′	1·23	15° 0′	3·41
30	0·19	30	1·37	30	3·64
4 0	0·24	10 0	1·52	16 0	3·87
30	0·31	30	1 67	30	4·12
5 0	0·38	11 0	1·84	17 0	4·37
30	0·46	30	2·01	30	4·63
6 0	0·55	12 0	2·19	18 0	4·89
30	0·64	30	2·37	30	5·17
7 0	0·75	13 0	2·56	19 0	5·45
30	0·86	30	2·76	30	5·74
8 0	0·97	14 0	2·97	20 0	6·03
30	1·10	30	3·19	30	6·33

Recurring to measurements for short distances, if the inclination be considerable, although the method first mentioned may be still applied, an entire chain's length cannot be measured at once; but the length of the incline must be taken in several short steps denoted in the annexed figure; whence the method is called stepping. It is seen here that the required horizontal distance, A B, is equal to the sum of the distances *a c*, *d e*, and *f g*.



If, however, the length of the line should exceed three chains, with considerable inclination, the measurements should be taken along the ground, and the true *horizontal* distance deduced from the *measured* distance, either by some instrument graduated to measure, roughly, either the angle of inclination, or, what would be much better, the correction to be deducted from the measured distance, or by some simple levelling instrument, such as the reflecting level described hereafter (p. 34). To the latter method we should give the preference; but instruments of various forms, termed *clinometers*, for measuring angles of inclination with sufficient accuracy for the purpose now under consideration, are constructed by the instrument makers, being also found useful for mining and draining.

A simple form of clinometer suitable for the purpose may be constructed as follows: Describe on a card, A, a semicircle about four inches diameter, and divide it into degrees; a card already divided for this purpose may be procured from the instrument maker: we have one procured from Messrs. Elliott, who also supply a similarly divided semicircle, mounted in wood. Procure a box, B B, about half an inch deep, with a glass face to it; fix the semicircle against the back of the box; and attach to the centre of the semicircle a fine cord, C C, with a small bullet, *b*, at the end, to act as a pendulum.



Make two circular apertures in the rim of the box, having their centres exactly in line with the diameter of the semicircle. The opening at o, to form the object-end

of the instrument, should be about a quarter of an inch in diameter, and should have a fine wire stretched across it horizontally, exactly in line with the diameter of the semicircle; and the aperture at *e*, to form the eye-end of the instrument, should be about the twentieth of an inch in diameter. In using it the height of the observer's eye from the ground should be conspicuously marked on an offsetting staff, described below, and a man being sent forward the required distance, to plant the staff on the ground and hold it in a vertical position, the sight is to be directed to the mark on the staff, and the pendulum, as soon as it is at rest, points to the degree of inclination, and to the correction to be made, if this also be marked on the card, as it is advisable that it should be.

The advantage of Gunter's chain consists in its adaptation to the superficial measure of land in acres, &c.; but when a survey is to be made for the purpose of linear measurements only, or when it may be more convenient to compute the area in square feet, a chain 100 feet long, divided into links of a foot long, is to be preferred. Such a chain is the best for military surveying.

Offsets, perpendicular to the main line, to hedges and remarkable objects on either side of it, are measured from the chain as it lies stretched upon the ground, by means of an offsetting staff. This staff should be 10 links in length, and divided into links. With Gunter's chain the staff, then, will be 6·6 feet, or 6 feet 7·2 inches long, while with the 100 feet chain it will be 10 feet in length.

The offsetting staff may be made of hickory, ash, or red pine. It should be about an inch and a quarter in diameter in the centre, tapering until it is about three-quarters of an inch diameter at the ends. One end should have a ferrule with steel point for sticking in the ground; and at the other end should be another ferrule with a strong hook fastened to the side, for the purpose of taking hold of one of the brass handles of the chain, when it is necessary to drag it through a hedge. The links should be marked with rings drawn round the rod, and cut in, and the centre should have some special mark, as a peculiar coloured ring, or a V, to denote five links. A surveyor might also keep by him one particular offsetting staff, marked conspicuously at a length denoting the height of his eye. Offsets are measured by laying the staff flat on the

ground, pointing to the spot to be measured to, and turning it over and forward, always pointing to the same spot.

Offsets may also be measured with a measuring tape very conveniently and accurately, and it is particularly convenient for the measurement of buildings, in surveying through a town. It requires, however, two persons to attend to it, and is liable to fray out and get dirty. Messrs. Parkes have taken out a patent for a tape, which they call the inflexible tape. It is woven from a strong fibre; and being saturated with a waterproof coating, is impervious to the effects of wet.

Surveys of small extent can be made with the chain only, and the mode of proceeding consists in chaining lines to form triangles, either included within, or inclosing, the area to be surveyed. The triangle, in fact, is the only figure the angular points of which can be determined by the lengths of the sides alone. The best form for the triangles is the equilateral, and they should, therefore, be made to approach this form as nearly as may be consistent with other important considerations. These considerations are that the chain lines should be as few as possible, and the offsets short. Lines across the triangles should be measured, thus forming new triangles, and checking the position of the angular points, common to them with the original triangles. Such lines are called *tie lines.*

It is best to have the principal triangles as large as possible; and, as it is of the greatest importance that the long lines necessary for this purpose should be made accurately straight, they must be marked out by station poles and ranging rods.

The station poles to be fixed at the ends of the principal lines should be fifteen or twenty feet long; they should be clean, straight, natural spars, and should be carefully fixed in a vertical position, by trying them with a line and plummet on every side.

The ranging rods should be about eight or nine feet long, and perfectly straight, shod with iron, and tipped with steel. They should be painted white; and both they and the station poles should have small flags fastened to their tops.

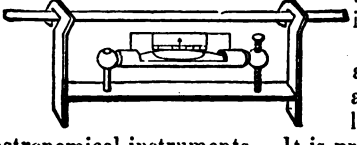
CHAPTER II.

INSTRUMENTS FOR THE MEASUREMENT OF VERTICAL DISTANCES.

THE SPIRIT LEVEL.

CERTAIN parts of the principal instruments used in surveying, and in astronomical observations, require to be adjusted in truly horizontal positions; and, to arrive at this adjustment, one or more subsidiary instruments, called *spirit levels*, are attached to such principal instruments. The spirit level attached to a good telescope, furnished with a compass, and such means of correct adjustment as we shall presently describe, becomes also itself an important instrument, being used in the department of surveying termed levelling, which consists in measuring the vertical distances between various stations.

The spirit level consists of a glass tube, differing from the cylindrical form by having its diameter largest in the middle, and decreasing slightly and with great regularity from the middle to the ends. The tube is nearly, but not quite, filled with spirits of wine, thus leaving in it a bubble of air, *b b*, which rises to the highest part of the tube, so as to have its two ends equally distant from the middle when the instrument is in adjustment, as represented in the annexed figure. The tube is generally fitted into another tube of metal, and attached to a frame terminating in angular bearings, by which the level can either be suspended from, or else be supported on, cylindrical pivots. When, however, the level forms a permanent part of any instrument, the manner of attaching it is modified to suit the particular form of the instrument to which it is attached. A small and accurately-divided scale is attached to the best instruments, or otherwise a scale is scratched upon the glass tube itself, as represented in the figure given above.



The annexed figure is a representation of such a level as is used for levelling the axis of the best astronomical instruments. It is provided with a fixed scale,

seen in the figure, and is suspended by means of accurately constructed angular bearings.

The following criteria of a good level are extracted from Dr. Pearson's valuable work on Practical Astronomy, before referred to.

"Firstly, the bubble must be long enough, compared with the whole tube, to admit of quick displacement, and yet not too long to admit of its proper elongation by low temperature.

"Secondly, the curve must be such, that the sensibility and uniform run of the bubble will indicate quantities sufficiently minute, while those quantities correspond exactly to the changes of inclination, as read on the graduated limb of the instrument of which it forms a part.

"Thirdly, the bubble must keep its station when the angles are moved a little round the pivots of suspension.

"Fourthly, the opposite ends of the bubble must vary alike in all changes of temperature, or, in other words, the ends of the bubble must elongate or contract alike in opposite directions, so that the middle point may always be stationary.

"Fifthly, the angles of the metallic end-pieces must be so nicely adjusted that reversion on horizontal pivots that are equal will not alter the place of the bubble.

"Sixthly, the distance between the two zeros of a fixed scale, when such a graduated scale is used, should be equal to the length of the bubble at the temperature of 60° of Fahrenheit's scale, and should be marked at equal distances from the visible ends of the glass tube. Then, as the bubble lengthens by cold or shortens by heat, its extreme ends may always be referred to these fixed marks, 0 0, on the scale, and will fall either within, upon, or beyond them, according to the existing temperature. The number of subdivisions of the scale that each end of the bubble is standing at, counted from the fixed zero marks, at the instant of finishing an observation, must always be noted, that an allowance may be made for the value of the deviation in seconds, or as the case may require.

"Seventhly, when the two ends of the bubble are not alike affected by a change of temperature, the scale should be a detached one, and adjustable to the new zero points, by an inversion of the level.

"*Eighthly, when the* scale has only one zero at its centre,

which is a mode of dividing the least liable to misapprehension, the positions must be reversed at each observation, and both ends of the bubble read in each position; for in this case, if any change has taken place in the true position of this zero, the resulting error will merge in the reduction of the observation. This mode of graduating is generally practised on the Continent."

We proceed now to the description of the most accurate instruments for measuring the differences of level, or vertical distances, between different stations.

Since the introduction of railways, the astonishing rate at which they have progressed, and the great amount of levelling work involved in their construction, have necessarily directed the attention, both of surveyors and instrument makers, to the production of an instrument which shall combine the advantages of expedition in its use, accuracy in the results obtained, and durability under the effect of constant wear and tear.

The best form is most undoubtedly the Y level; and the best construction of Y level has resulted from the adaptation of the Dumpy level to this form. We shall, therefore, proceed first to the complete description of the Y level with its adjustments, premising that, in other forms of level, not possessing the same facility for correcting the adjustment at any time, the adjustment must be made by the maker, in the manner here described, before finally fixing the parts of the instrument; and dependence must then be placed upon its solidity, and the accurate and close construction of all the joints, for the permanency of correct adjustment.

DOLLOND'S Y LEVEL.

The following figure represents this instrument. A is an achromatic telescope, resting upon two supporters, which in shape resemble the letter Y, and are consequently called the Y's. The lower ends of these supporters are let perpendicularly into a strong bar, which carries a compass box C. This compass box is convenient for taking bearings, and has a contrivance for throwing the needle off its centre, when not in use. One of the Y supporters is fitted into a socket, and can be raised or lowered by the screw B.

Beneath the compass box, which is generally in one piece with the bar, is a conical axis passing through the upper of

two parallel plates, and terminating in a ball supported in a socket. Immediately above this upper parallel plate is a

collar, which can be made to embrace the conical axis tightly by turning the clamping screw E, and a slow horizontal motion may then be given to the instrument by means of the tangent screw D. The two parallel plates are connected together by the ball and socket already mentioned, and are set firm by four mill-headed screws, which turn in sockets fixed to the lower plate, while their heads press against the under side of the upper plate, and thus serve the purpose of setting the instrument up truly level.

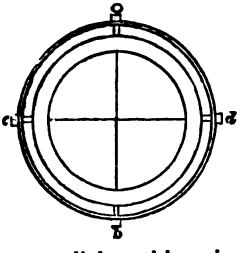
Beneath the lower parallel plate is a female screw, adapted to the staff-head, which is connected by brass joints with three mahogany legs, so constructed as, when shut together, to form one round staff, a very convenient form for portability, and, when opened out, to make a very firm stand, be the ground ever so uneven.

The spirit level *l l* is fixed to the telescope by a joint at one end, and a capstan-headed screw at the other, to raise or depress it for adjustment.

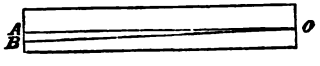
In looking through a telescope a considerable field of view is embraced; but the measurements, indicated by any instrument, of which the telescope may form a part, will only have

reference to one particular point, which particular point is considered as the centre of this field of view. We must therefore place some fixed point in the field of view, at the focus of the eye-piece, and the point to which the measurement will have reference will be that point of the object viewed, which appears to be coincident with this fixed point, or which, as the technical phrase is, is bisected by the fixed point.

The intersection of two fixed lines will furnish us with such a fixed point, and, consequently, two lines of spider's thread are fixed at right angles to each other in the focus of the eye-piece. They are attached by a little gum to a brass ring of smaller dimensions than the tube of the telescope, and which is fixed to the tube by four small screws, *a*, *b*, *c*, *d*. If the screw *d* be eased, while at the same time *c* is tightened, the ring will be moved to the right; but if *c* be eased, and *d* tightened, the ring will be moved to the left; and, in a like manner, it may be moved up or down by means of the screws *a* and *b*.



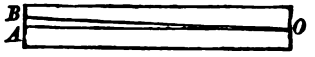
When the instrument is in adjustment, the axis of the tube of the telescope is set truly horizontal by means of the level beneath it, and the line of observation ought consequently to be parallel to this axis. Let A represent the proper position of the intersection of the cross wires, and *o* A the direction of the axis of a pencil of light passing through the object-glass and coming to its focus at A. Then, the axis of the tube of the telescope being set truly horizontal, the line A *o* is also truly horizontal, and every point bisected by the intersection of the cross wires will be situated on the prolongation of the horizontal line A *o*.



Suppose now the position of the diaphragm carrying the cross wires to have become deranged, so that the point of intersection is moved to B, then every point bisected by the intersection of the cross wires will be on the prolongation of the line B O, and will, consequently, be below the true level point on the line A O.

Let now the telescope be turned half round in the Y's, and

let the annexed figure represent it in its new position; then, in this new position of the telescope, the prolongation of the line B *o* will rise above the prolongation of the level line



A *o*, and, at the same distance from the telescope, the point now bisected by the intersection of the cross wires will be as much above the true level point on the line A *o*, as the point before bisected by them was below it. The true level point is, therefore, midway between the two points observed in the two positions of the telescope, and the diaphragm carrying the cross wires is to be moved by means of the screws, *a*, *b*, *c*, *d*, till their point of intersection coincides with that true level point. The telescope is then to be again turned round upon the Y's, and if the same point be still bisected by the intersection of the cross wires, they are in their proper position; but if not, the same method of adjustment must be repeated, till the same point is bisected by the intersection of the cross wires in every position of the telescope.

The error from misplacement of the spider-lines has a technical denomination. The line *o* A, or *o* B, from *o* to the point of intersection of the cross wires, is called the *line of collimation*, and the error arising from their derangement, which we have shown the method of detecting, and correcting, is called the *error of collimation*.

When the image of the object viewed, formed by the object-glass, falls either short of, or beyond, the place of the cross wires, the error arising from this cause is called *parallax*. The existence of parallax is determined by moving the eye about when looking through the telescope, and observing whether the cross wires change their position, and are flittering and undefined.

To correct this error, first adjust the eye-piece by means of the movable eye-piece tube, till you can perceive the cross wire clearly defined and sharply marked against any white object. Then by moving the milled-headed screw A, at the side of the telescope, the internal tube, *a a*, is to be thrust outwards or drawn inwards, until you obtain the proper focus, according to the distance of the object, and you are enabled to see, at the same time, the object clearly, and the intersection of the wires,

clearly and sharply defined, before it. The existence of parallax is very inconvenient, and, where disregarded, has frequently been productive of serious error. It will not always be found sufficient to set the eye-piece first, and the object-glass afterwards. The setting of the object-glass, by introducing more distant rays of light, will affect the focus of the eye-piece, and produce parallax, or indistinctness of the wires, when there was none before: the eye-piece must, in this case, be adjusted again.

Generally, when once set for the day, there is no occasion for altering the *eye-piece*, but the *object-glass* will of course have to be altered at every change of distance of the object.

In adjusting the instrument, the parallax should be first corrected, and then the error of collimation. The line of collimation being thus brought to coincide with the axis of the tube of the telescope, two further adjustments are necessary: the first to adjust the bubble-tube, so that it may truly indicate when the axis of the telescope is horizontal; and the second to set the axis of the telescope perpendicular to the vertical axis round which the instrument turns.

To adjust the Bubble-Tube.—Move the telescope till it lies in the direction of two of the parallel plate screws, and by giving motion to these screws bring the air-bubble to the centre of its run. Now reverse the telescope carefully in the Y's, that is, turn it end for end; and should the bubble not settle at the same point of the tube as before, it shows that the bubble-tube is out of adjustment, and requires correcting. The end to which the bubble retires must then be noticed, and the bubble made to return one-half the distance by turning the parallel plate screws, and the other half by turning the capstan-headed screw at the end of the bubble-tube. The telescope must now again be reversed, and the operation be repeated, until the bubble settles at the same point of the tube, in the centre of its run, in both positions of the instrument. The adjustment is then perfect, and the clips which serve to confine the telescope in the Y's should be made fast.

The bubble-tube has sometimes three vertical screws at one end instead of a single screw to adjust it. By this means the tube can be adjusted to horizontal as well as vertical parallelism with the axis of the telescope. This adjustment is tested by gently rocking the telescope round

in the Y's, through a small angle on either side of the position it occupies. When the level-tube is properly placed, the correction, if required, is made with the three vertical screws, by pushing or pulling the level-tube from the end the bubble travels towards, when brought round a small portion of a turn; a very slight touch of the screws will suffice.

Lastly, to set the Axis of the Telescope perpendicular to the Vertical Axis round which the Instrument turns.—Place the telescope over two of the parallel plate screws, and move them, unscrewing one while screwing up the other, until the bubble of the level settles in the centre of its run; then turn the instrument half round upon the vertical axis, so that the contrary ends of the telescope may be over the same two screws, and, if the bubble does not again settle at the same point as before, half the error must be corrected by turning the screw B, and the other half by turning the two parallel plate screws over which the telescope is placed. Next turn the telescope a quarter round, that it may lie over the other two screws, and repeat the process to bring these two screws also into adjustment; and when, after a few trials, the bubble maintains exactly the same position in the centre of its run, while the telescope is turned all round upon the axis, this axis will be truly vertical, and the axis of the telescope being horizontal by reason of the previous adjustment of the bubble-tube, will be perpendicular to that vertical axis, and remain truly horizontal while the telescope is turned completely round upon the stand. The adjustment is therefore perfect.

The object of the above adjustments is to make the line of collimation move round in a horizontal plane, when the instrument is turned round its vertical axis, and the methods above explained suppose that the telescope itself is constructed with the utmost perfection, so that the axis of the tube carrying the object-glass is always in the same straight line with the axis of the tube which carries the diaphragm with the cross wires. If this perfection in the construction of the instrument does not exist, the line of collimation will vary as the tube carrying the object-glass is thrust out and drawn in, to adjust the focus for objects of different distances.

In the best constructed instruments, however, of whatever pattern, the collimation, having been adjusted by the maker by the *methods* detailed above, is scarcely liable to derange-

ment afterwards. We do not, therefore, think much advantage would be derived from any plan of collimating a badly-constructed instrument. If the axis of the tube which carries the diaphragm moves accurately in a straight line, although this line should not be the same with the axis of the tube carrying the object-glass, the points viewed, when the focus is correctly adjusted for each observation, will lie in a straight line, which can be made horizontal, and when from a dropping of the tube as it is drawn out, or a curvilinear motion produced either by inferior workmanship originally, or from having received some subsequent injury, we know of no means of collimation by which such a defect can be remedied, and it can only be put right by the hands of the instrument maker.

Mr. Gravatt published a method of collimating with the view of removing the error arising from imperfection in the slides of the telescope, and at the same time eliminating the small errors arising from the curvature of the earth and the horizontal refraction. The error, however, arising from the imperfection of the slide cannot be removed, unless the maker can improve the motion of the tubes; and the most that Gravatt's mode of collimating can do is so to divide the error arising from the readings at different distances as to diminish its importance. With respect to the errors arising from the curvature of the earth and from refraction, as they are almost, if not entirely, eliminated by the method of taking the levels from positions nearly equi-distant from the station observed, as usually practised, the advantage of considering them in any mode of collimating is extremely problematical.

We subjoin, however, Mr. Gravatt's mode of collimating, which may be used to test the motion of the diaphragm, if we have reason to fear that it does not move in a straight line; but for levels in which, as in the Dumpy, the telescope cannot be reversed on its bearings, a simpler mode of testing, and, if necessary, of adjusting the collimation is to be preferred.

To examine and correct the Collimation by Mr. Gravatt's Method.—"On a tolerably level piece of ground, drive in three stakes, at intervals of about four or five chains, calling the first stake *a*, the second *b*, and the third *c*.

"Place the instrument half way between the stakes *a* and *b*, and read the staff A, placed on the stake *a*, and also the staff B, placed on the stake *b*; call the two readings A and B;

then, although the instrument be out of adjustment,* yet the points read off will be equi-distant from the earth's centre, and consequently level.

"Now remove the instrument to a point half way between *b* and *c*. Again read off the staff B, and read also a staff placed on the stake *c*, which call staff C (the one before called A being removed into that situation). Now, by adding the difference of the readings on B (with its proper sign) to the reading on C, we get three points, say A′, B′, and C′, equidistant from the earth's centre, or in the same true level.

"Place the instrument at any short distance, say half a chain beyond it, and, using the bubble merely to see that you do not disturb the instrument, read all three staffs, or, to speak more correctly, get a reading from each of the stakes, *a*, *b*, *c*; call these three readings A″, B″, C″. Now, if the stake *b* be half way between *a* and *c*,† then ought $C'' - C' - (A'' - A)$ to be equal to $2\,[B'' - B' - (A'' - A')]$; but if not, alter the screws which adjust the diaphragm, and consequently the horizontal spider line, or wire, until such be the case; and then the instrument will be adjusted for collimation.

"To adjust the spirit-bubble without removing the instrument, read the staff A, say it reads A‴, then adding $(A''' - A')$ with its proper sign to B′ we get a value, say B‴.

"Adjust the instrument by means of the parallel plate screws,‡ to read B‴ on the staff B.

"Now, by the screws attached to the bubble-tube, bring the bubble into the centre of its run.

"The instrument will now be in complete practical adjustment for level, curvature, and horizontal refraction, for any distance not exceeding ten chains, the maximum error being only $\frac{1}{1000}$th of a foot."

Gravatt's method of collimating is objectionable from its

* The axis of the instrument is to be set vertical by means of the parallel plate screws, by placing it over each pair alternately, and moving them until the air-bubble remains in the same position, while the instrument is turned half round upon its axis.

† Whatever be the distances between the stakes *a*, *b*, *c*, the following proportions ought to hold, viz.:—

The distance from *a* : *b* : the distance *a* to *c* : : $B'' - B' - (A'' - A')$: $C'' - C' - (A'' - A')$: if not the diaphragm does not move in a straight line.

‡ If this adjustment be made by the screw B, instead of the parallel plate screws, the line of collimation will be brought into its proper *position with respect to* the vertical axis.

needless complexity in the case of a good instrument, and from its failing to correct a bad one, since the curvilinear motion of the diaphragm, if any, which it indicated, can only be set right by the instrument maker.

To test and adjust, if necessary, the Collimation of a Level, the following simple method is the best:—If a pool of water large enough be at hand, drive in two stakes, three or four chains apart, exactly level with the surface of the water. If no such pool of water be convenient, select a piece of ground as nearly level as possible, and drive in two stakes, three or four chains apart, until the readings obtained from a point midway between them be exactly the same for each: then, if the instrument have been set up with its axis truly vertical, the tops of the two stakes will be exactly on the same level, as is the case with the stakes in the pool of water.

Set up the instrument in the line of the stakes, about half a chain beyond one of them; then if the readings of the staff, placed alternately on each of the stakes, be the same, the line of collimation is correct; but if not, alter the position of the diaphragm, until exactly the same reading is obtained from both stakes, and the collimation will be adjusted.

The instrument having been carefully examined and rectified, in using the instrument the screw B should never be touched; but at each station the parallel plate screws alone should be used for setting the axis round which the instrument turns truly vertical, when, in consequence of the adjustments previously made, the line of collimation will be truly level. For this purpose the telescope must be placed over each pair of the parallel plate screws alternately, and they must be moved till the air-bubble settles in the middle of the level, and the operation being repeated till the telescope can be turned quite round upon the stand, without any change taking place in the position of the bubble, the instrument will be ready to read off the graduations upon the levelling staves, which we proceed to describe.

GRAVATT'S DUMPY LEVEL.

To Mr. Gravatt is undoubtedly due the credit of having, in the construction of the Dumpy level, led the way to all the improvements which have recently been made in this instrument, terminating in the improved Y level, than which we

can imagine nothing better adapted to satisfy all the requisites of a perfect instrument.

We shall here merely mention the characteristic points of Gravatt's level; and its construction, and mode of adjustment by the maker, as well as the method of using it, will be fully understood from the detailed description of the Y level (p. 12).

This instrument is furnished with an object-glass of large aperture and short focal length; and, sufficient light being thus obtained to admit of a high magnifying power in the eye-piece, the advantages of a much larger instrument are

secured, without the inconvenience of its length: hence has arisen the name of Dumpy, given to the instrument. The diaphragm is carried by the internal tube, *a a*, which is nearly equal in length to the external tube. The external tube, T T, is sprung at its aperture, and gives a steady and even motion to the internal tube, *a*, *a*, which is thrust out, and drawn in, to adjust the focus for objects at different distances, by means of the milled-headed screw A. The spirit level is placed above the telescope, and attached to it by capstan-headed screws, one at either end, by means of which the bubble can be brought to the centre of its run.

The telescope is attached to a horizontal bar, but room is just left between the telescope and the bar for the compass-box. By this means the instrument is rendered very firm and compact, in comparison with the old instrument, in which the level was placed below the telescope.

A cross level, *k*, is placed upon the telescope at right angles to the principal level, *l*, *l*, by which we are enabled to set the instrument up at once with the axis nearly vertical. This is intended to give the advantages of expedition in setting the instrument, and saving in the wear and tear of the parallel plate screws. From its extreme shortness, however, *it does* not perform its duty well, and to give it

greater length, to a sufficient extent to be really useful, would be very inconvenient, and it would be then very liable to disarrangement.

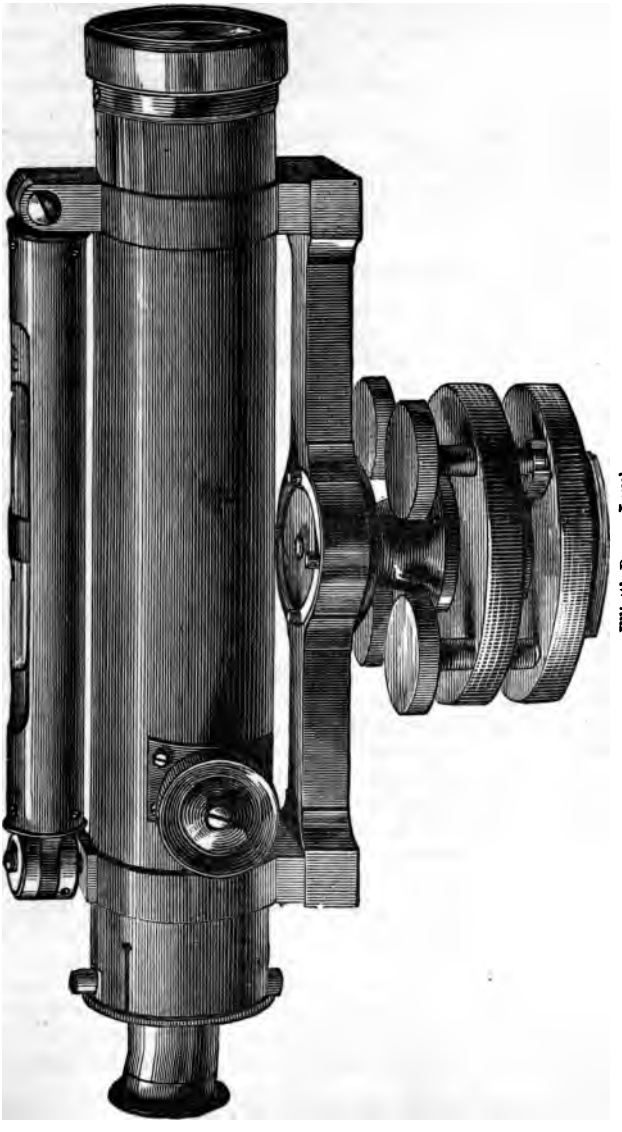
A mirror, *m*, mounted upon a hinge-joint, is placed at the end of the level *l*, *l*, so that the observer, while reading the staff, can at the same time see that the instrument retains its proper position—a precaution by no means unnecessary in windy weather, or on bad springy ground.

The telescope is attached to the horizontal bar by capstan-headed screws, B, B, by which the line of collimation is set perpendicular to the vertical axis; and the instrument is set up upon parallel plates, as will be understood from the description of the Y level.

ELLIOTT'S IMPROVED DUMPY LEVEL

In Gravatt's, as in levels previously constructed, the level, telescope, and horizontal bar were made in one piece, and the parallel plate, with conical axis, formed a head-piece to which the former was screwed when in use. Now a tighter or slacker connection between the telescope and the parallel plate portion of the instrument would produce a disparagement, which would manifest itself in the impossibility of making the bubble maintain the centre of its run, whilst the instrument was turned completely round on its axis. For this reason it is imperative always, in levels so fixed to the parallel plates, to turn them constantly to the right, and never to the left, in adjusting them and pointing them for use. If they were often turned to the left, not only would their correctness be certainly injured, but they might even get screwed off, and fall.

In the level now under consideration, the horizontal bar and conical axis are in one piece, and cannot be disunited, so that the level, telescope, and parallel plates are not adapted for separation, or liable to the disarrangement which accompanies it. Secondly, the horizontal bar is made so as to have its principal thickness and strength in the vertical direction, and not in the horizontal, where there is neither any strain nor any material injury that could be produced by a strain. Thirdly, the cross-level *k* is removed, and a circular level *is placed below* the telescope instead of the compass box.



Elliott's Dumpy Level.

This adds considerably to the simplicity and compactness of the instrument; and this form of level, being equally sensitive in every direction, is admirably adapted for the first rough adjustment of the instrument by moving the legs of the tripod stand.

In levelling, the ground passed over has always been previously surveyed, and, besides, the bearing, if required, can be taken with a pocket compass of the ordinary construction, or with a prismatic compass, better than with one attached to the level.

THE IMPROVED DUMPY Y LEVEL.

This instrument differs from the improved Dumpy level last described only in resting the telescope upon Y-shaped bearings attached to the horizontal bar, instead of being permanently fixed to this bar; and when in adjustment, the telescope is held in position by clips attached to the Y's. One of the Y supporters may be fitted in a socket, as in the ordinary Y level, already described, and may be raised or lowered by a capstan-headed screw; or the required effect may be produced by carefully rubbing off slight portions of the surface of one of the Y's.

LEVELLING STAVES.

The best constructed levelling staff consists of three parts, which pack together by sliding, in a neat manner, and, when drawn out for use, make a staff from 14 to 17 feet long; the bottom joint is about four inches wide; and the whole length is divided into hundredths of a foot, coloured black and white alternately. The feet and tenths are numbered, the figures for the tenths being always painted black, while those for the feet are distinguished by their larger size, and often also by being painted red. In the annexed figures, Fig. 1 shows the whole of one foot, reduced to *one-fourth* of the actual size, and Fig. 2 shows a length of sixteen-hundredths of a foot, *full* size. Every alternate tenth is numbered with a figure, the length of which exactly occupies a tenth: the top of the figure 1, for instance, being exactly in line with the top of the black division, which measures one-tenth of a foot from the base of the staff, and the bottom of the figure 3 being in line with the top of the black division, which measures two-tenths of a foot from the base. It will also be seen that all the horizontal

lines in the figures are also in line with some particular hundredths on the scale: the bottom of the top stroke of the 3 with twenty-eight hundredths, the top of central portion with twenty-six hundredths, the bottom of this portion with twenty-five, and the top of the bottom portion with twenty-two hundredths. This arrangement is an assistance in reading the division off, and, when long sights are required, every assistance of this kind is valuable. All the even hundredths reach to the top of a black stroke, and all the odd hundredths, to the

Fig. 1.

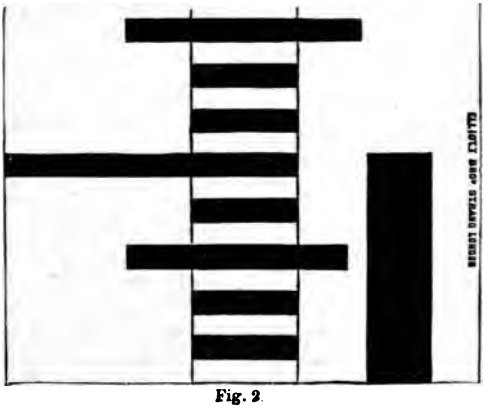


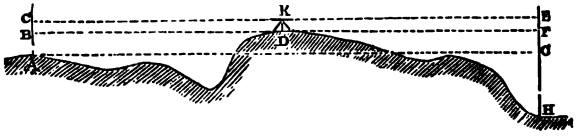
Fig. 2.

bottom of a black, or top of a white stroke. The graduations for feet may also be made additionally conspicuous by painting a border on the left hand side of the staff, alternately black and white, the black and white divisions each occupying the length of a foot, and a vertical white band, about three-eighths of an inch wide, being left between the border and the column of graduations.

It is to be observed that, when viewed through the telescope, the *staff* appears inverted, as well as the figure upon

it, the telescope having an astronomical eye-piece, to avoid the loss of light that would be incurred by the use of a terrestrial or erecting, eye-piece. This produces no inconvenience, the eye soon becoming familiar with their appearance in this form, and readily reading the figures downwards, as in fact an upward measurement from the ground.

Levelling.—The operation of determining the difference of level between two stations, by observations made at a single station, is called *simple levelling*, and is performed as follows:—



Let A and H be two points whose difference of level is required. Plant the instrument at D, and adjust it to a horizontal position. Read off A C, the height of a staff held at A, then turn the telescope round and read off E H, the height of a similar staff, or of the same staff held at H. Then A C is the height of K, the axis of the telescope above the point A, and E H is the height of K above another point H; and it is clear that E H − A C = G H, the difference of level between A and H.

In this operation the station A, at which the staff is first read off, is called the back station, and the station H is called the fore station; and, if the reading of the staff at the back station be greater than that at the fore station, the difference of level is called a rise; but if the reading at the back station be less than that at the fore, as in the example just given, the difference of level is called a fall.

When from the nature of the ground, or the great distance between the two points, they cannot both be observed from a single spot, a series of simple levels must be taken, the fore station at each operation being made the back station at the next operation; and from the combination of all the results thus obtained the required difference of level is found. In these operations, care must be taken, in going over soft ground, lest the staff at the fore station, when turned round to be read as the staff at the back station in the next operation, should sink farther into the ground; and, to prevent this,

the foot of the staff must be placed upon a flat, hard substance as a piece of slate or tile. There is a simple instrument called a tripod, sold for this purpose by the instrument makers, being simply a plate of iron with a small rounded projection in the centre, two small spikes at the side to fix it in its place, and a short chain to lift it by, when the staff-holder wishes to remove from his place.

In determining by this method the difference of level between two distant points, it is immaterial by what route we proceed from one to another, so that such spots may be selected for the intermediate stations as are most convenient for the purpose. The bearings of the stations from the instrument are also matter of indifference; but the more nearly the instrument is equidistant from the two stations observed at each operation, the more correct will be the result obtained, the errors in the back readings compensating, for the most part, the errors in the fore readings, whether the errors arise from refraction* and curvature,† or from the imperfect adjustment of the instrument. The sum of the distances from the instrument to the fore stations should also be nearly equal to the sum of those to the back stations.

If, then, the object be only to obtain the difference of level of two points, we have only to record in two separate columns the readings of the staff at the back stations and fore stations respectively, and the difference of the sums of these readings will be the difference of level required. Thus, if the difference of level between two points A and B be required, and if the readings at A and B, and three intermediate stations ⊙ 1, ⊙ 2, ⊙ 3, be recorded as follows, viz.:—

* The error of refraction is that arising from the bending of the rays of light during their passage through the atmosphere, and makes all objects appear higher than they really are.

† The object of levelling is to determine points upon a spherical surface or equally distant from the earth's centre, or to determine the differences of the distances of a series of points from the earth's centre. The line of sight, or prolongation of the line of collimation, however, is a tangent to the spherical surface, and therefore the points observed upon this line are really above the level of the point of observation. The correction for curvature is therefore additive, while that for refraction is subtractive.

		Back ⊙	Fore ⊙		
		Feet.	Feet.		
Reading of staff at	A	3·65	5·80	Reading of staff at	⊙ 1
"	⊙ 1	2·05	8·50	"	⊙ 2
"	⊙ 2	3·89	8·40	"	⊙ 3
"	⊙ 3	5·28	14·35	"	B
		14·87	37·05		
			14·87		
			22·18		

Then 22·18 feet is the fall from A to B, or A is 22·18 feet above B.

When, however, it is required not only to find the difference of level between two distant points, but to make such observations as shall enable us to draw a section, exhibiting the undulations of the ground along some specified route from the one point to the other, then the stations must be so chosen, that one of them shall be at the commencement of each change in the inclination of the ground; the distances between the stations must also be carefully measured; and it is further advisable to note the distances and bearings of the stations from the instrument, which it will be more convenient now to place on a point in the specified route between the stations. The bearings may be best taken with a prismatic compass, described hereafter (p. 40); but the compass attached to the instrument will do, if there be one, or any pocket compass may be used.

In drawing the section, it is the horizontal distances between the several stations that must be laid down. For short distances, or over very irregular ground, such horizontal measurements may be obtained by bidding an assistant hold one end of a measuring tape close to the ground at the highest end of the distance, and holding the other end above the ground, stretching the tape in a horizontal line, a stone let fall from this end then marking upon the ground the point to which the measurement reaches. But, when the ground rises and falls in long regular slopes, the measurements should be taken along the slopes, and then be reduced to horizontal distances by calculation. If the rise or fall is but slight, this reduction may be altogether disregarded, the difference between the horizontal and hypothenusal measurements not *exceeding the limits* of error in the measurements themselves

Care should be taken to record all the observations in a clear and intelligible form, and for this purpose a field book may be prepared of the accompanying form.

	Distance to stations.		Bearings.	Staff readings.		Heights above datum.	Reduction.	Reduced horizontal distances.	REMARKS.
	From starting point.	From instruments.		Back.	Fore.				
	feet.	feet.	°			feet.			
Back ⊙		210	30·000	100·00 3·65		100·00			Back ⊙ 300 feet from hedge, windmill bearing 125° from instrument, church spire bearing 223·5°.
						3·65 103·65			
Fore ⊙	460	250	120·10		5·80	5·80 97·85			
Back ⊙	460	180	300·00	2·05		97·85			Road to lime kilns.
						2·05 99·90			
Fore ⊙	320 780	140	120·00		8·50	8·50 91·40			
Back ⊙	780	180	299·75	3·89		91·40			
						3·89 95·29			
Fore ⊙	380 1160	200	119·40		8·40	8·40 86·89			
Back ⊙	1160	180	300·25	5·28		86·89			
						5·28 92·17			
Fore ⊙	360 1520	180	120·00		14·35	14·35 77·82			
Back ⊙	1520	300	300·00	12·25		77·82			
						12·25 90·07			
Fore ⊙					15·78	15·78 74·29			Bottom of canal distant 150 feet.
Back ⊙				15·78		74·29			
						15·78 90·07			
Fore ⊙	580 2100	280	120·00		9·21	9·21 80·86			
Back ⊙	2100	205	300·15	11·05		80·86			
						11·05 91·91			
Fore ⊙	400 2500	195	120·00		1·12	1·12 90·79			
		2500		153·95 63·16 90·79	63·16				

In the first column are entered the distances between the several stations, which, being successively added to the preceding total, give the total distances of each station from the starting-point; in the next column are entered the distances of the stations from the instrument; and in the third, are entered the bearings of the stations from the instrument. In the fourth and fifth columns are entered the readings of the staves; and in the sixth column the heights above datum of the several stations are computed, by adding the back reading to the height last found, and subtracting the fore reading from the sum. The seventh and eighth columns are added for performing the reduction of the measured distances to horizontal distances, when the slope is sufficient to render this reduction necessary. In carrying forward the distances to the next page of the book, the total reduced horizontal distance should be carried to the top of the first and second columns, instead of the total measured distance along the slope; but such substitutions should not be made at any other part of the page, as it would interfere with the proof of the distances by adding up the second column, which ought to produce the last distance entered in the first. The levels are proved by subtracting the sum of the numbers in the fifth column from the sum of the numbers in the fourth, when the remainder should be the height above datum of the last station, recorded at the bottom of the sixth column.

To facilitate the reduction of the measured distances to the corresponding horizontal distances, the following table, showing the reduction, upon each 100 feet, for each foot difference of level, should be inserted in the field book:—

Difference of Level in 100 feet distance.	Reduction upon 100 feet of distance.	Difference of Level in 100 feet distance.	Reduction upon 100 feet of distance.	Difference of Level in 100 feet distance.	Reduction up n 100 feet of distance.
4	0·08	13	0·85	22	2·45
5	0·13	14	0·98	23	2·68
6	0·18	15	1·13	24	2·92
7	0·25	16	1·29	25	3·18
8	0·32	17	1·46	26	3·44
9	0·41	18	1·63	27	3·71
10	0·50	19	1·82	28	4·00
11	0·61	20	2·02	29	4·30
12	0·72	21	2·23	30	4·61

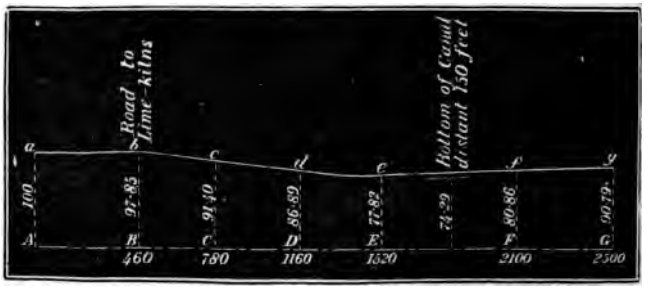
When it is required to plot the section on a large scale,

and to show every undulation of the surface, it is not necessary to remove and re-set the instrument, to obtain the height above datum of every point necessary to be known for this purpose; but, besides reading the staff at the back and fore stations, it may be read off, from the same place of the instrument, at as many intermediate points as may be deemed desirable; and these readings, being entered both as back and fore readings, will produce the same effect, as back and fore readings of the same points, obtained in different positions of the instrument. The distances of these points from the instrument should be omitted from the second column; but, the distances between them being entered successively in the first column, their respective distances from the instrument may at any time be determined, if required. The height of the instrument itself may be entered in this way as an intermediate sight; and as the same height that is added as a back reading, is subtracted again as a fore reading, any error in this reading will not at all affect the levels afterwards taken, and, provided it be not greater than the limit within which distances can be laid down and estimated upon the plot, is of no moment. Now, in taking the section of a line of any considerable extent, the scale is seldom sufficiently large to admit of less than six inches being laid down, or estimated, upon the plot, and, consequently, an error of two or three inches in the intermediate sights would be immaterial. When observations are made out of the line to be levelled, in order, for instance, to obtain the height of this line above neighbouring rivers, canals, roads, &c., the readings are to be entered in the same manner as for other intermediate sights; and, the columns of bearing and distance being left blank, no mistake can be made in drawing the section. The bearing and distance of such points, if desirable to be noted, must be entered in the space left for remarks.

For the purpose of reference on any future occasion, in order either to check the accuracy of the levels already obtained, or for the convenience of commencing a new series in some other direction, marks should be left upon some convenient fixed points, upon which the staff has been held, and the reading noted with the greatest possible care. These bench marks, as they are called, should ordinarily be left at about every half-mile of distance, and may be either on or off the line. In the *latter case* the readings are to be recorded in

the manner already explained for points out of the line. The hooks and tops of gates, copings, sills, or steps of doors, &c., are commonly used for bench marks, and the mark must be made exactly on the point upon which the staff has been held. A stout stake may be driven into the ground for a bench mark, and is by many persons preferred to any other.

When a section of considerable length is to be plotted, the horizontal distances cannot be laid down on as large a scale as is necessary for the vertical heights above datum, in order that the section may be of any practical use, without making the plot of most unwieldy dimensions. It is therefore usual



to make the vertical scale much larger than the horizontal one: thus 4 inches to a mile for the horizontal distances, with one inch to 100 feet for the vertical distances, is a usual combination. In the accompanying figure we have drawn the portion of a section, from the portion of the field book at page 29, making use of a scale of 1 inch to 800 feet for the horizontal distances, and of a scale of 1 inch to 200 feet for the vertical distances.

A G is ruled for the datum line; on it are set off from A the horizontal distances at the points B, C, D, E, F, G, according to the horizontal scale of 1 inch for each 800 feet, and through the points A, B, C, D, E, F, and G, are drawn lines A*a*, B*b*, &c., perpendicular to A G; on these lines are set off the vertical distances to the points *a*, *b*, *c*, &c., according to the vertical scale of 1 inch for each 200 feet; and the line *a g*, passing through all the points *a*, *b*, *c*, &c., will represent the required section. A line is drawn between the stations E and F at the proper distance from the datum line, to represent

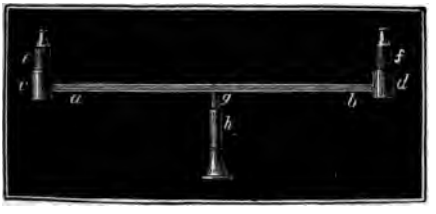
the level of the canal; and proceeding in this manner, and making any remarks that may seem desirable, opposite the corresponding points of the section, the work will be completed.

LEVELS FOR CONTOURING, MINING, DRAINING, ETC.

Having now explained the construction and use of the most perfect instrument for tracing the level of any portion of country, we proceed to notice instruments adapted for use in cases where rapidity of execution is of greater importance than minute accuracy.

THE WATER LEVEL.

A very simple instrument of this kind is the *water level.* It can be made anywhere, and by any workman, costs but a few shillings, and requires no adjustment when using it.



a b is a hollow tube of brass, about half an inch in diameter, and about 3 feet long; *c* and *d* are short pieces of brass tube, of larger diameter, into which the long tube is soldered. and are for the purpose of receiving the two small bottles, *e* and *f*, the ends of which, after the bottoms have been cut off, by tying a piece of string round them when heated, are fixed in their positions by putty or white lead; the projecting short axis, *g*, works, in the instrument from which the sketch was taken, in a hollow brass cylinder, *h*, which forms the top of a stand, used for observing with a repeating circle; but it may be made in a variety of ways, so as to revolve on any light portable stand. The tube, when required for use, is filled with water, coloured with lake or indigo, till it nearly reaches to the necks of the bottles, which are then corked for the convenience of carriage. On setting the stand tolerably level by the eye, these corks are both withdrawn, which must be done

carefully, and when the tube is nearly level, or the water will be ejected with violence; and the surface of the water in the bottles, being necessarily on the same level, gives a horizontal line in whatever direction the tube is turned.

THE REFLECTING LEVEL.

An instrument, however, with which observations upon the level of a country may be more expeditiously made, and generally with greater correctness, than with the water level, is the reflecting level. This instrument consists merely of a piece of common looking-glass, *l l*, 1 inch square, set in a frame fixed against a plate of metal weighing about a pound, and suspended from a ring, *r*, by a twisted wire, *w*, so that it may swing freely, but not turn round on its axis of suspension. A fine silk thread, *t t*, is stretched across the centre of the mirror, and a small opening, *o*, is at one side of the mirror.

The instrument is adjusted as follows. It is suspended at about 50 yards in front of a wall. The observer looks into the mirror, and brings his eye into such a position that its image is bisected by the silk thread *t t*; and the point upon the wall, seen through the opening, *o*, which coincides with the silk thread, is marked upon the wall. The mirror is then turned round, and when the silk thread again bisects the image of the observer's eye, the point, the reflection of which in the mirror now coincides with this thread, is also marked upon the wall. Lastly, the middle point, between the two thus found, is marked upon the wall; and, by turning a screw, *s*, the centre of gravity of the instrument is altered, till the mirror hangs so that the reflection of the last mark comes upon the thread, when the observer's eye is also bisected by it. The instrument will now be in perfect adjustment, and, when the image of the eye is brought upon the thread, all points bisected by the thread, whether seen by reflection, or directly through the opening *o*, will be on the same level with the eye of the observer.

The observations may be made either by holding the

instrument at arm's length, or by suspending it from the branch of a tree, or from any post or rail of a convenient height. Greater accuracy is obtained by suspending it by means of a frame fitting on a three-legged stand, such as already described, as used for supporting the more accurate instruments; but it must not be forgotten that this instrument is not to be at all compared with them for minute accuracy; but that its advantages are the great rapidity with which it can be used, whether in a very confined space, or in an open country.

IMPROVED REFLECTING LEVEL.

All the advantages of the instrument just described are possessed in a higher degree by the improved reflecting level, which resembles it in nothing but the name, and the fact that

a reflector is used in its construction. It is a small portable instrument, which requires no adjustment, can be taken from the pocket at any time, and used immediately.

It consists of a tube, *a b*, about six inches long, and three-quarters of an inch in diameter; one end, *a*, forming the eye-end, being closed by a disc, pierced with a sight-hole of about the twentieth of an inch in diameter. A spirit-level, *l l*, is placed over a slit made in the tube, so that the bubble can be reflected from a mirror placed within the tube. This mirror, *m*, fills up half of the tube, and being inclined to the axis of the tube, at an angle of 45 degrees, reflects along the axis, a ray falling upon it at right angles to this axis. The level, then, being so placed that a line drawn from the centre of its run to the edge of the mirror is at right angles to the axis of the tube, the bubble, being at the centre of its run when the axis of the tube is horizontal, is then seen in the direction of the axis by an eye applied to the eye-end of the instrument; and consequently, upon looking through the tube, that point of any object, which is in coincidence with the image of the bubble must be on the same level as the eye of the observer.

We have received from Messrs. Elliott an instrument, in

which the mirror is made to fill half the tube on one side, so that its edge appears as a vertical diameter, instead of being horizontal. A fine wire is then placed across the tube at right angles to the edge of the mirror; and, when the

image of the bubble is bisected by this wire, any point, seen through the tube in coincidence with the wire, is on the same level as the eye of the observer. This mode of construction is a very great improvement.

The reflecting level is a very useful instrument for contouring, that is, for determining lines upon the ground, which would form the boundaries of horizontal sections of its surface. For this purpose the observer has the height of his eye marked upon a staff, and an assistant, carrying this staff, plants it upon the ground at short intervals, and moving to the right or left, according to signals from the observer, until the mark is seen on a level with the observer's eye, a series of points on the desired contour line are determined. A second mark being made upon the staff at a known distance below the first, a point differing in level from the contour already determined by this distance, or by any multiple of it, may be determined, and, the observer proceeding to this point, another contour is determined passing through it; and so a series of contours is ultimately found at equal differences of level, which, being laid down on a plan previously constructed, delineates all the undulations of the plot represented by that plan. The distances to the points at which the observations are made, from points previously determined, should be taken with a measuring tape, and the points can thence be easily laid down on the paper.

Draining and Mining Levels.—For the purposes of mining and draining, instruments adapted to measure the rise or fall for each 100 feet of distance are found convenient. The illustrations annexed, taken from instruments forwarded to us by Messrs. Parkes, give the forms of two such levels.

In Fig. 1, the telescope A B is attached at the object-end to the bar C D by the hinge-joint H, and this bar is attached to a second bar F, by the spring *k*, and pivot *p*. The bar F screws

on to an axis G, fitted to the head of a tripod stand, and the bar C D, being approximately levelled by moving the legs of the stand, is brought truly horizontal by turning the screw S until the level comes to the centre of its run. The eye-end, A, of the telescope is attached to the bar C D by the arc R R, and is moved along this arc by means of a rack and pinion, moved by the screw T. The arc R R is graduated, to show the rise and fall in every 100 feet of distance, and is read by means of an index seen through the small circular opening *e*. The bubble is adjusted by the capstan-headed screw X.

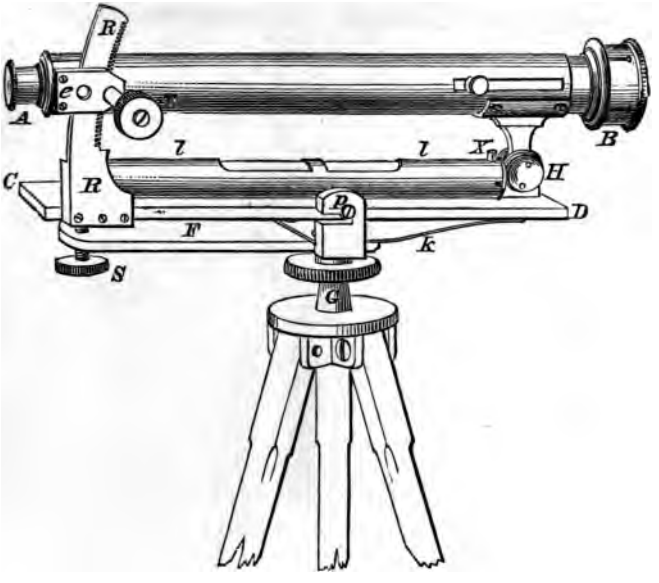


Fig. 1.

To adjust the Bubble—Set the telescope with the index at 0; then, planting the instrument about half a chain beyond one of two stakes, driven into the ground until their tops are on the same level, turn the screw S, until the same reading is obtained from a levelling staff, placed alternately on each of the stakes; if then the bubble be in the centre of its run, the

adjustment is perfect; but if not, make it come to the centre of its run by turning the screw x.

This is an inexpensive instrument, and is used with great facility. For instance, to construct a drain with a given fall per 100 feet, set the index to the figure indicating the given fall, and then the differences of the readings on a staff, placed on different stations along the route of the drain, will indicate the

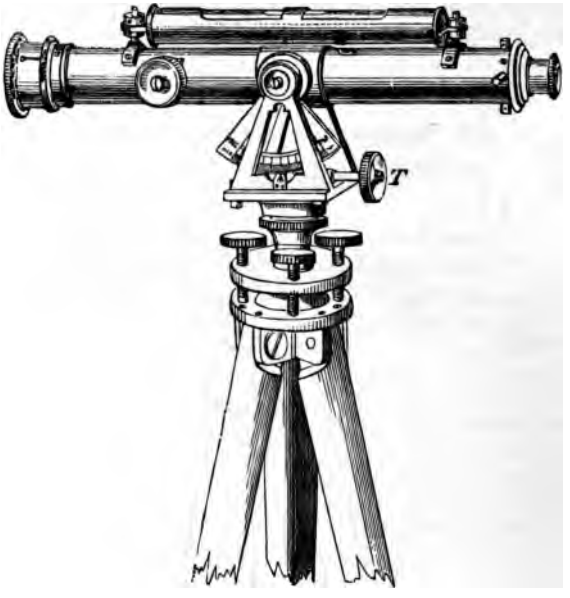


Fig. 2.—(Scale one-fourth.)

differences of the depths to which to go at these points, to come to the position for the bottom of the drain.

Fig. 2 represents a more expensive instrument. It can be used to take both back sights and fore sights, or sights in any direction, since it is mounted on parallel plates, and can be used in the same manner as a Dumpy, or other surveying level: in fact, the index being first set to zero on the arc beneath the telescope, the adjustments are then the same for

this instrument as for a Dumpy level. To determine a line of rise or fall, the graduated arc must be moved by means of the tangent screw T, until the index points to the rise or fall desired. This instrument can then be used in the same manner as the one last described. In that instrument, however, there is no means of setting the axis vertical, and, consequently, that instrument must be adjusted, by bringing the bubble to the centre of its run, at each observation, though made from the same station.

CHAPTER III.

INSTRUMENTS FOR MEASURING ANGLES.

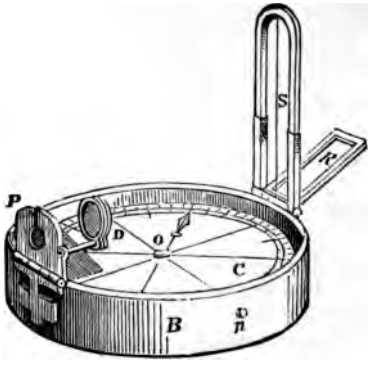
In every map and plan the distances and angles laid down are not the actual distances and angles between the points, the relative positions of which are intended to be represented; but they are the distances and angles between the projections* of those points upon the same horizontal plane, and are called the horizontal angles and distances between the points. Now, if our surveying instruments were constructed to measure the actual angles subtended by different objects, the process of calculating all the horizontal angles from these observed angles would be very laborious; but, by having such instruments as will at once determine by observation the horizontal angles, we are saved a vast amount of labour, and also from errors which might creep into the calculations.

THE PRISMATIC COMPASS.

With this instrument horizontal angles can be observed with great rapidity, and, when used with a tripod stand, with a considerable degree of accuracy. It is, consequently, a very valuable instrument to the military surveyor, who can make

* The projection of a point upon a horizontal plane is the point in which a *vertical line* through that point meets the horizontal plane.

his observations with it, while holding it in his hand, with all the accuracy necessary for a military sketch. It is also a useful instrument for filling in the detail of an extensive survey,* after the principal points have been laid down by means of observations made with the theodolite, hereafter to be described, and for any purpose, in short, in which the portability of the instrument and rapidity of execution are of more importance than extreme accuracy.



C is a compass card divided usually to ev ry 20′, or third part of a degree, and having attached to its under side a magnetic needle, which turns upon an agate centre, O, fixed in the box B; *n* is a spring, which, being touched by the finger, acts upon the card, and checks its vibrations, so as to bring it sooner to rest, when making an observation. S is the sight-vane, having a fine thread stretched along its opening, by which the point to be observed with the instrument is to be bisected. The sight-vane is mounted upon a hinge-joint, so that it can be turned down flat into the box when not in use. P is the prism, attached to a plate sliding in a socket, and thus admitting of being raised or lowered at pleasure, and also supplied with a hinge-joint, so that it can be turned down into the box when not in use. In the plate to which the prism is attached, and which projects beyond the prism, is a narrow slit, forming the sight through which the vision is directed when making an observation. On looking through this slit, and raising or lowering the prism in its socket, distinct vision of the divisions on the compass card immediately under the sight-vane is soon obtained, and these divisions, seen through the prism,

* The prismatic compass was used for this purpose by the gentlemen engaged in making the Ordnance surveys.

all appear, as each is successively brought into coincidence with the thread of the sight-vane by turning the instrument round, as continuations of the thread, which is seen directly through the part of the slit that projects beyond the prism.

The method of using the instrument is as follows:—The sight-vane S, and the prism P, being turned up upon their hinge-joints as represented in our figure, hold the instrument as nearly in a horizontal position as you can judge, or, if it be used with a tripod stand, set it, as nearly as you can, in a horizontal position by moving the legs of the stand, so that the card may play freely. Raise the prism in its socket, till the divisions upon the card are seen distinctly through the prism, and, turning the instrument round, until the object to be observed is seen, through the portion of the slit projecting beyond the prism, in exact coincidence with the thread of the sight-vane, bring the card to rest by touching the spring *n*; and then the reading at the division upon the card, which appears in coincidence with the prolongation of the thread, gives the magnetic azimuth of the object observed, or the angle which a straight line, drawn from the eye to the object, makes with the magnetic meridian.* By repeating each observation two or three times, and taking the mean of the readings, greater accuracy in the measurement of the bearings will be obtained; and, to ensure the most correct results, the observer, after observing an object two or three times, should proceed to the place of that object, and again observe an object at his first station the same number of times, taking the readings from the north in the first case, and from the south in the second, or *vice versâ:* the mean of all the results in these to be taken as the correct reading. This method will also detect any local attraction

* The magnetic meridian now makes an angle of about 24° with the true meridian, at London, the north point of the compass being 24° west of the true north point. This angle is called the variation of the compass, and is different at different places, and also at the same place at different times. Since this variation will affect equally, or nearly so, all azimuths observed within a limited extent, and during a limited time, the angles subtended by any two of the objects observed, being the difference of their azimuths, will not be affected by the variation, and hence the map, or plan, may be constructed with all the objects in their proper relative positions; but the true meridian must be laid down, *if required,* by observations made for the purpose.

on the needle, that may be acting at the one station, and not at the other. The magnetic azimuth of a second object being obtained in the same manner, the difference between these two azimuths is the angle subtended by the objects at the place of the eye, and, which is an important point, is independent of any error in the azimuths, arising from the slit in the prism not being diametrically opposite to the thread of the sight-vane.

For the purpose of taking the bearings of objects much above or below the level of the observer, a mirror, R, is supplied with the instrument, which slides on and off the sight-vane, S, with sufficient friction to remain at any part of the vane that may be desired. It can be put on with its face either upwards or downwards, so as to reflect the images of objects, either considerably above or below the horizontal plane, to the eye of the observer; and, if the instrument be used for obtaining the magnetic azimuth of the sun, it must be supplied with dark glasses, D, to be interposed between the sun's image and the eye.

There is a stop in the side of the box, not shown in our figure, by touching which a little lever is raised, and the card thrown off its centre, as it always should be when not in use, or the constant playing of the needle would wear the fine agate point upon which it is balanced, and the sensibility of the instrument would be thereby impaired. The sight-vane and prism being turned down, a cover fits on to the box, which is about three inches in diameter, and one inch deep; and the whole, being packed in a leather case, may be carried in the pocket without inconvenience.*

The compass card being divided into 360°, the degrees are numbered, in some instruments, from the north point round by the east, south, and west, to the north again, from 0° up to 360°, consecutively, the 0° not being figured, since it coincides with the 360°; there is, consequently, no need to mention more than the angular reading, to describe the exact bearing, which is all easterly. Thus, an object bearing exactly south-east, would be fully described by the angular

* For much valuable information respecting the use of the prismatc compass, especially in military surveying and sketching, we can refer our readers to a "Treatise on Military Surveying," &c., by Lieutenant-Colonel Basil Jackson, in which the subject is handled with great ability.

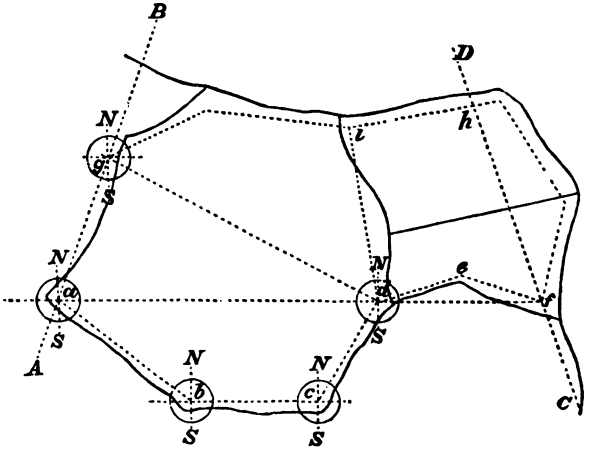
reading 135°, that is, 135° from the north round by the east, and an object bearing south-west, would be described by the angular reading 225°, that is, 225° from the north round by the east. In other instruments, the degrees are figured from the north, round by the east, to the south, up to 180°, and then, commencing again at 0°, from the south, round by the west, up to 180° again at the north. The bearing of an object may then be described by giving the angular reading, with the direction east or west, since all bearings reading east, go progressively from north to south, and all bearings reading west, go progressively from south to north.

The following illustrations of the use of the prismatic compass are taken from Haskoll's "Practice of Engineering Field Works."

"Let A B and C D be portions of two main chain lines of a survey; it is required to fill in the fencing along *a b c d e f*. From the point *a*, take the bearings of *a* B and of *a f*, *f* being a station on the line C D, previously fixed on for this purpose. Fix on some object in the fence near some point, for instance, *d*, in line with *a f*. Take also the bearing of *a b*, and chain to *b*, offsetting as you go along, and at *b* take the bearing point of *b a*; and if *a b* bear 136° East, then *b a* should bear 136° West. If there is a difference of a few minutes between the readings, take the mean for the correct reading. At *b* and at *c* repeat the same kind of work. On reaching *d*, find this station on the line *a f*; take the bearings of *d a* and of *d f*; and whatever number of degrees one is West from South, the other will be East from North. In the four-sided figure *a b c d*, the four angles will be equal to four right angles, or 360°; and as, having the bearings, we can obtain the angles from them, we can ascertain how nearly our bearings make these angles equal to four right angles. If, as is almost sure to be the case with this instrument, we get some few minutes, either over or under the four right angles, divide this difference among the bearings. It is also possible, that from *d* we may be able to get a bearing of some known point on the line A B, by which, when we come to plot, we may check the position of *d*; for if *d g* reads 130° West, then, the plotting from *g* on the plan of a line bearing 130° East, will run through the station *d*, when this has also been plotted. For the continuation of the work from d to e and f, we have a

triangle *d e f*, the three internal angles of which should be equal to two right angles, by which we may check the angles at *d*, *e*, and *f*. It cannot fail to be observed that all the bearings may, and should, be plotted from the station *a*, without once moving the protractor.

"As we consider it very desirable that the student should make himself thoroughly master of the prismatic compass, before he engages with the principal surveying instrument, the theodolite, we will go a little further into this matter, premising, however, that it will be more as an introduction,



than anything else, to what is termed surveying by traverse, to which we shall come at a future page. Probably, also, it will make the subject more familiar to the reader, when he comes to it.

"At *a*, let the bearing of *a d* be 91° 5′ East, and the bearing of *a b*, 136° East; note this, at the commencement of the line *ab*, before you commence chaining. On reaching the point *b*, take the bearing of *b a*, and let this be 136° 5′: note this at the end of the line, and take 136° 2½′ for the mean, or corrected bearing, east and west, of the line, *a b*. In the same manner, let the mean bearing of *b c* equal 89°,

and that of *c d*, equal 30°. At *d*, take the bearing of *d a*, and let this be 91° 10′; then the mean or corrected bearing of *a d*, or *d f*, will be equal to 91° 7½′. The angle *d a b* is equal to 136° 2½′, minus 1° 7½′, or 44° 55′. The angle *a b c* is made up of the angles *a b* N, and N *b c*; *a b* N is equal to 180° minus 136*b* 2½′, or to 43° 57½′; and, N *b c* being 89°, the angle *a* ₒ *c* is equal to 43° 57½′, plus 89, or to 132° 57½′. The angle *b c d* is made up of the angles *b c* N, and N *c d*; *b c* N is equal to 180° minus 89°,* or to 91°; and, N *c d* being 30°, *b c d* is equal to 91°, plus 30°, or 121°. Lastly, *c d a* is equal to S *d a* minus S *d c*; S *d a* is equal to 91° 7½′; and, *s d c*, being 30°, *c d a* is equal to 91° 7½′ minus 30°, or to 61° 7½′."

Now 44° 55′ + 132° 57½′ + 121° + 61° 7½′ = 360°.

In the same manner we may check the triangle *d e f*, the three angles of a triangle being equal to two right angles.

Observe that three more lines for filling in have been run, from *g*, on A B, to *h*, on C D; and that a tie line has been chained from *d* to *i*, forming a further check upon the work; for, if in plotting, *d* or *i* lean one way or the other out of position, then the line *d i* will not plot truly.

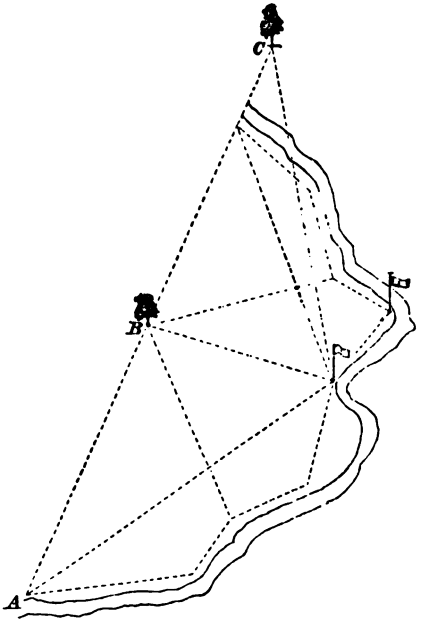
For the operation of filling in, the large 5-inch prismatic compass with silver ring is very useful, and, when once the surveyor has become familiar and handy with the use of the instrument, it will give very close approximations.

To plot the bearings, place the protractor at *a*, so that A B shall have its due bearing with regard to the magnetic meridian N S, the north and south being each represented on the protractor by 180°; prick off, from *a*, the bearings of *a f*, *a b*, *b c*, *c d*, *d e*, *e f*; from *a* draw *a f* and *a b*, making the latter the length of the measured chain line; and from *b*, *c*, *d*, and *e*, draw *b c*, *c d*, *d e*, and *e f*, parallel to their bearings pricked off from *a*, and make them of lengths corresponding to the measured chain distances.

With due attention this instrument may also be used for a road survey. The bearings along the bends of the road are taken at the same time that the lengths are chained, care being

* A straight line falling on two parallel straight lines makes the two internal angles on the same side of it together equal to two right angles; it also makes the alternate angles equal to one another. —*Euc. Bk. I. Prop. 29.*

taken, also, to get bearings from several stations to one or two objects, likely to be visible from different parts of the survey. The work is plotted as before, by laying off the bearings all from one point. The figure illustrates a similar method of getting a plan of a stream; but here a visual line A B C, has been set off, passing through two prominent objects, selected for the purpose. As the bearings of the chain lines along the banks of the stream are measured, a few bearings



are taken here and there, at different stations, upon the prominent objects, and if convenient, one or two back sights upon the starting-point. If the chain lines have been correctly measured, and the bearings correctly taken. these bearings upon the prominent objects will all intersect very near the objects, and prove the degree of accuracy of the work; and though, it must be remembered, we cannot

expect the same amount of accuracy as with a theodolite, yet, if the prismatic compass be applied in the manner we have been pointing out, errors will be inappreciable. The measurement of the bases A B and B C will completely check the work.

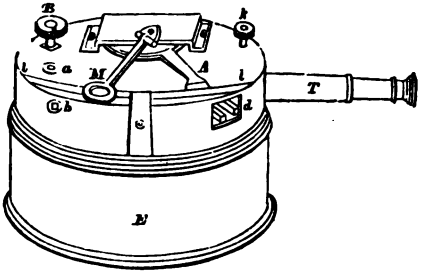
There is yet another service to which the prismatic compass is well adapted, which is, from their bearings, to ascertain the angles that fences make with chain lines, more particularly those straight fences which do not require offsetting. If, in the course of filling in, such a fence be intersected by two chain lines, the intersections, of course, fix the direction of the fence upon the plan; and a check upon the chaining is afforded by the use of the prismatic compass in the manner here mentioned. It may also be rendered very useful in testing the accuracy of a plan, the correctness of which we have any reason to doubt. Draw two or three lines across the plan, and marking on it the angles they make with each other; then in the field set out the corresponding lines with ranging rods, take their bearings, and see if the angles between them agree with those measured upon the plan. This may also be done without rods, by drawing any line on the plan through two or three junctions of fences, setting off the corresponding line on the ground, taking the angles that adjacent fences make with this line, and then comparing these angles with those similarly made on the paper.

THE BOX SEXTANT.

This instrument, which is equally portable with the prismatic compass, forming, when shut up, a box of about three inches in diameter, and an inch and a half deep, will measure the actual angle between any two objects to a single minute. It requires no support but the hand, is easily adjusted, and, when once adjusted, but seldom requires re-adjusting.

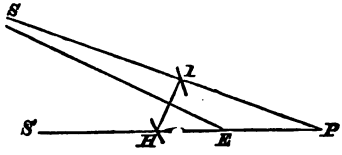
When the sextant is to be used, the lid, E, of the box is taken off, and screwed on to the bottom, where it makes a convenient handle for holding the instrument. The telescope, T, being then drawn out, the instrument appears as represented in our figure. A, is an index arm, having at its extremity a vernier, of which 30 divisions coincide with 29

of the divisions upon the graduated limb *l l*; and the divided spaces upon the limb denoting, each, 30 minutes, or half a degree, the angles observed are read off, by means of the vernier, to a single minute. The index is moved by turning the milled head, B, which acts upon a rack and pinion within the box. To the index arm is attached a mirror, called the index glass, which moves with the index arm, and is firmly fixed upon it by the maker, so as to have its plane accurately perpendicular to the plane in which the motion of the index arm takes place, and which is called the plane of the instrument. This plane is evidently the same as the plane of the face of the instrument, or of the graduated limb *l l*. In the line of sight of the telescope is placed a second glass, called the horizon glass, having only half its surface silvered, and which must be so adjusted that its plane may be perpendicular to the plane of the instrument, and parallel to the plane of the index glass when the index is at zero. The instrument is provided with two dark glasses, which can be raised or lowered by means of little levers seen at *d*, so as to be interposed, when necessary, between the mirrors, and any object too bright to be otherwise conveniently observed, as the sun. The eye-end of the telescope is also furnished with a dark glass, to be used when necessary.



The principle upon which the sextant is constructed has been proved (vol. ii. p. 4), viz.: that the total deviation of a ray of light, after reflection successively at the index glass and horizon glass, is double the inclination of the two glasses. Now, the limb *l l*, being divided into spaces, each of 15′ extent, and these spaces being figured at 30′ each, the reading of the limb gives double the angle moved over by the index arm from the position in which the reading is zero, or double the angle of inclination of the two mirrors, I and H, if these mirrors be parallel when the reading is zero. If, then,

the instrument be in perfect adjustment, and any object be viewed by it after reflection at both the mirrors, the reading of the instrument gives the total deviation of the rays of light, by which the vision is produced, or the angle S P H between the bearing of the object, S, from the centre of the index mirror, I, and the bearing of the reflected image, S′, from E, the place of the eye, that is, between lines, S I and S′ E, drawn, respectively, from the object to the centre of the index glass, and from the reflected image in the horizon glass to the eye. This angle is very nearly equal to the angle S E H, subtended by the object and its image at the place of the eye, differing from it only by the small angle I S E, subtended at the object by the place of the eye, and the centre of the index glass. This small angle is called the parallax of the instrument, and is scarcely perceptible at the distance of a quarter of a mile, while for distances greater than that it is so small that it may be considered to vanish. It also varies with the amount of deviation, and vanishes altogether whenever the centre of the index glass is in a direct line between the object and the eye.*



To see if the instrument be in perfect adjustment, place the dark glass before the eye-end of the telescope, and looking at the sun, and moving the index backwards and forwards a little distance on either side of zero, the sun's reflected image will be seen to pass over its disc, as seen directly through the horizon glass, and if, in its passage, the reflected image completely covers the direct image, so that but one perfect orb is seen, the horizon glass is perpendicular to the plane of the instrument; but if not, the screw at *a* must be

* We have seen a method given for what is called correcting the parallax when an observation is made at a short distance, by finding the deviation at this distance, when the angle between the object and its image is equal to zero; this deviation being given by the reading of the instrument, when the reflected image of the object observed exactly coincides with the object itself, seen through the unsilvered part of the horizon glass. This deviation, however, is not the parallax, even for a small angle between the object and its image, and, if the angle be not very small, the error introduced by the method will be greater than the parallax itself.

turned by the key *k* till such is the case. The key *k* fits the square heads of both the screws seen at *a* and *b*, and also fits into a spare part of the face of the instrument, so as to be at hand when wanted. This adjustment being perfected, bring the reflected image of the sun's upper limb in exact contact with the direct image of his lower limb, and note the reading of the vernier; then move the index back beyond the zero division of the limb, till the reflected image of the sun's lower limb is in exact contact with the direct image of his upper limb, and, if the zero of the vernier be now exactly as far behind the zero of the limb, as it was, at the former reading, in front of it, so that the reading now on the part of the limb called the arc of excess, behind its zero division,* is the same as the former reading, the instrument is in perfect adjustment; but, if not, half the difference of the two readings is the amount of the error, and is called the index error, being a constant error, for all angles observed by the instrument, of excess, if the first reading be the greatest, and of defect, if the second reading on the arc of excess be the greatest.

In the former case, then, the true angle will be found by subtracting the index error from, and in the latter, by adding it to, the reading of the instrument at every observation.

This method of correcting for the index error is to be used with the larger instruments, hereafter to be described under the head of Astronomical Instruments; but in the box sextant, this error should be removed by applying the key *k* to the screw at *b*, and turning it gently, till both readings are alike, each being made equal to half the sum of the two readings first obtained. When this adjustment is perfected, if the zeros of the vernier and limb are made exactly to coincide, the reflected and direct image of the sun will exactly coincide, so as to form but one perfect orb, and the reflected

* In reading an angle upon the arc of excess, the division to read on the limb is that next in front of the zero of the vernier, or between the zero of the vernier and the zero of the limb, and the divisions of the vernier itself are to be read from the end division marked 30, and not, as usually, from the zero division: thus, if the zero division of the vernier were a little farther from the zero division of the limb, than the first division on the arc of excess; and if the twenty-seventh division on the vernier, or the third from the end division, marked 30, coincided with a division upon the limb, then the reading would be 33.

and direct image of any line, sufficiently distant not to be sensibly affected by parallax, as the distant horizon, or the top or end of a wall more than half a mile off, will coincide so as to form one unbroken line.

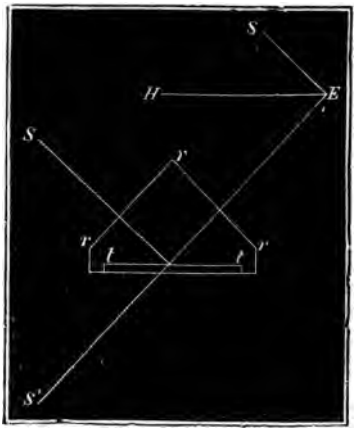
To obtain the angle subtended by two objects, situated nearly or quite in the same vertical plane, hold the instrument in the right hand, and bring down the reflected image of the upper object, by turning the milled head B till it exactly coincides with the direct image of the lower object, and the readings of the instrument will give the angle between the two objects.

To obtain the angle subtended by two objects nearly in the same horizontal plane, hold the sextant in the left hand, and bring the reflected image of the right-hand object into coincidence with the direct image of the left-hand object.

It will be seldom that the surveyor need pay any attention to the small error arising from parallax; but, should great accuracy be desirable, and one of the objects be distant, while the other is near, the parallax will be eliminated by observing the distant object by reflection, and the near one by direct vision, holding the instrument for this purpose with its face downwards, if the distant object be on the left hand. If both objects be near, the reflected image of a distant object, in a direct line with one of the objects, must be brought into coincidence with the direct image of the other object, and the parallax will thus be eliminated.

For the purposes of surveying, the horizontal angles, between different objects, are required, and the reduction of these angles from the actual oblique angles, subtended by the objects, would be a troublesome and laborious process. If the angle subtended by two objects be large, and one be not much higher than the other, the actual angle observed will be, however, a sufficient approximation to the horizontal angle required; and, if the angle between the two objects be small, the horizontal angle will be obtained, with sufficient accuracy, by taking the difference of the angles observed between each of the objects, and a third object, at a considerable angular distance from them. With a little practice the eye will be able to select an object in the same direction as one of the objects, and nearly on a level with the other object, and the angle between this object, and the object selected, will be the horizontal angle required.

At sea the altitude of an object may be determined by observing the angle subtended by it and the verge of the horizon; but upon land a contrivance, called *an artificial horizon*, becomes necessary, for correctly determining altitudes. The best kind of artificial horizon consists of an oblong trough, *t t*, filled with mercury, and protected from the wind by a roof, *r r*, having in either slope a plate of glass with its two surfaces ground into perfectly parallel planes. The angle, S E S′, between the object, and its reflected image seen in the mercury, is double the angle of elevation S E H; and, the angle S E S′ being observed, its half will, consequently, be the angle of elevation required. If the angle of elevation be greater than 60°, the angle S E S′ will be greater than 120°, and cannot be observed with the sextant we have been describing.

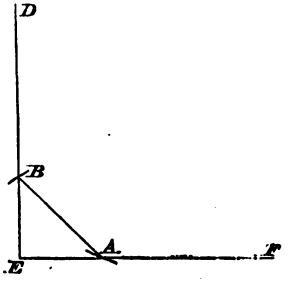


The box sextant is a most convenient instrument for laying off offsets, or perpendicular distances from a station line; for, by setting the index at 90°, and walking along the station line, looking through the horizon glass directly at the farther station staff, or any other remarkable object upon the station line, any object off the station line will be seen by reflection, when the observer arrives at the point where the perpendicular from this object upon the station line falls; and the distance from this point to the object being measured, is its perpendicular distance from the station line.

For the mere purpose of measuring offsets an instrument called an *optical square* is now very generally employed, which consists of the two glasses of the sextant fixed permanently at an angle of 45°, so that any two objects seen in it, the one by direct vision, and the other by reflection, subtend at the place of the observer an angle of 90°.

THE OPTICAL SQUARE.

The mirrors A and B are fixed in a shallow circular box, so that the vertex E of the isosceles right-angled triangle A B E comes to the circumference of the box, where the aperture for the eye is placed. By this means parallax is eliminated, and a ray of light from the object F, proceeding in the direction F E, and falling upon the mirror A, is reflected in the direction A B, meets the mirror B, is again reflected in the direction B E, and seen by the eye at E, in the direction E D, at right angles to E F. The mirror B is unsilvered in the lower part, so that the eye, looking along the line E D through the aperture in the rim of the box, sees an object D in this line, by direct vision, in coincidence with the reflected image of the object F, on the line E F, at right angles to E D.



This instrument cannot be excelled for facility and rapidity of use. To set off a perpendicular from a given point on a line, the observer, standing at this point, and holding the square in his hand, directs the motions of an assistant, who walks out from the line with a rod, so as to keep the reflection of the rod in the mirror B, in coincidence with an object, on the line, seen through the unsilvered portion of the same mirror: the line from the observer's eye to the rod, is, then, the perpendicular required.

Again, if a perpendicular is to be made to fall from a given point upon a given line, the observer walks along the line, until he comes to a point from which he sees an object on the line, coinciding with the image, in the mirror B, of an object at the given point: the observer is then standing at the spot, on which the perpendicular will fall.

THE CROSS STAFF.

Another instrument for setting out lines at right angles to other lines, is the cross staff, which, though old fashioned and cumbrous, is still very commonly used for the purpose.

There are two forms of cross staff. One form consists of four sights fixed at right angles upon a brass cross, which, when in use, is fixed on the top of a staff. The second form consists of a hollow brass cylinder, about three or four inches in diameter, and as many in depth, through which are pierced sights at right angles to each other: this also, when in use, is affixed to a staff.

To set out with the cross staff a perpendicular to a line, from a given point on it, thrust the staff into the ground at this point, so that through one pair of sights you can see both ends of your main line, by looking first through one of these sights, and then moving round and looking through the opposite one. Having thus ensured a point exactly on the line, and the proper position of the cross, now move round, and, looking across the instrument, through the other pair of sights, have a pole set up in a line with them; and the perpendicular will be set off.

THE LINE RANGER.

We may here notice another application of the law of

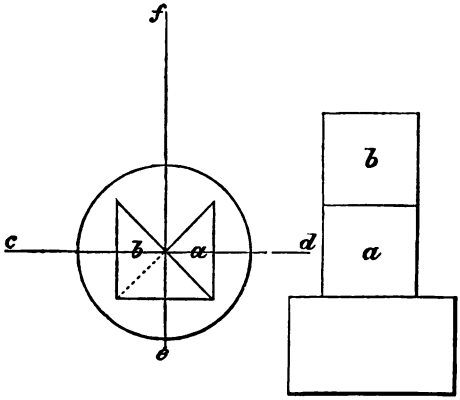


Fig. 1. *Fig.* 2.

reflected light, to the determination of the relative angular position of objects, in Adie's line ranger, a very simple pocket instrument, for setting out straight lines. It is shown in plan

in Fig. 1, and in elevation in Fig. 2. *a* and *b* are two totally reflecting glass prisms, placed one over the other, on a cylindrical base, which serves as a handle. One of the faces of the right angle in the upper prism, is placed flush with one of the faces of the right angle in the lower prism, the other faces containing the right angles being parallel. The observer, holding the instrument in his hand, and looking into the prisms in the direction *e f*, sees directly before him, in the prism *a*, the reflected image of a pole at *d*, on his right hand, and in the prism *b*, that of another at *c*, on his left hand; and, when these images are in the same straight line, the instrument is also exactly in the same straight line with the objects *c* and *d*.

THE THEODOLITE.

The theodolite is the most important instrument used by surveyors, and measures, at the same time, both the horizontal angles subtended by each two of the points observed with it, and the angles of elevation of these points from the point of observation.

This instrument may be considered as consisting of three parts: the parallel plates with adjusting screws fitting on to the staff head, of exactly the same construction as already described for supporting the Y and other levels; the horizontal limb, for measuring the horizontal angles; and the vertical limb, for measuring the vertical angles, or angles of elevation.

The horizontal limb is composed of two circular plates, L and V, which fit accurately one upon the other. The lower plate projects beyond the other, and its projecting edge is sloped off, or chamfered, as it is called, and graduated at every half degree. The upper plate is called the vernier plate, and has portions of its edge chamfered off, so as to form with the chamfered edge of the lower plate continued portions of the same conical surface.* These chamfered portions of the upper plate are graduated to form the verniers,

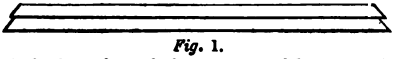
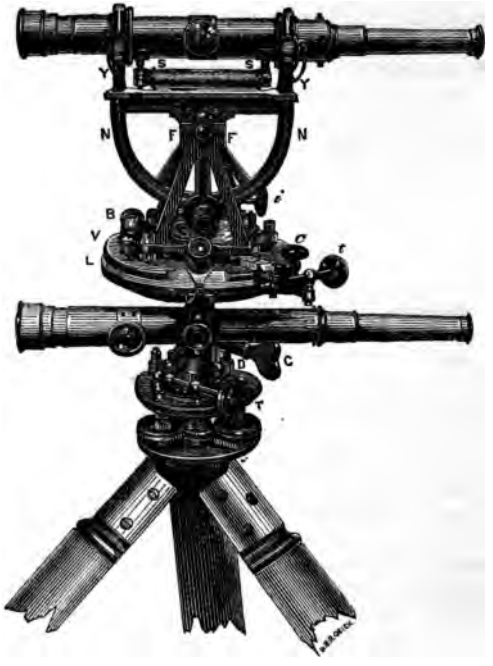


Fig. 1.

* In the ordinary mode of construction, represented in section in Fig. 1, the perfect coincidence of the junction of the upper and lower plates cannot be effected; but the edge of the vernier plate, slightly overlapping the lower, may produce a small error in the reading, from the

by which the limb is subdivided to single minutes. The six-inch theodolite represented in our figure has two such verniers, 180° apart. The lower plate of the horizontal limb is attached to a conical axis passing through the upper parallel



Dollond's six-inch Theodolite, with 2 Telescopes.

plate, and terminating in a ball fitting in a socket upon the lower parallel plate, exactly as the vertical axis of the Y level already described. This axis is, however, hollowed to receive

introduction of parallax. This defect has been remedied in some theodolites by squaring the edges, at the junction between the two plates, as represented in Fig. 2.

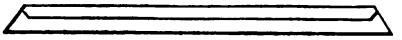


Fig. 2.

a similar conical axis ground accurately to fit it, so that the axes of the two cones may be exactly coincident or parallel.* To the internal axis the upper, or vernier, plate of the horizontal limb is attached, and thus, while the whole limb can be moved through any horizontal angle desired, the upper plate only can also be moved through any desired angle, when the lower plate is fixed by means of the clamping screw, C, which tightens the collar D. T is a slow-motion screw, which moves the whole limb through a small space, to adjust it more perfectly, after tightening the collar, D, by the clamping screw C. There is also a clamping screw, c, for fixing the upper, or vernier, plate to the lower plate, and a tangent screw, *t*, for giving the vernier plate a slow motion upon the lower plate, when so clamped. Two spirit levels, B, B, are placed upon the horizontal limb, at right angles to each other and a compass, G, is also placed upon it in the centre, between the supports, F, F, for the vertical limb.

The vertical limb, N, N, is divided upon one side, at every 30 minutes, each way, from 0° to 90°, and subdivided by the vernier, which is fixed to the compass box, to single minutes. Upon the other side are marked the number of links to be deducted from each chain, for various angles of inclination, in order to reduce the distances, as measured along ground, rising or falling at these angles, to the corresponding horizontal distances. The axis of this limb must rest, in a position truly parallel to the horizontal limb, upon the supports F, F, so as to be horizontal, when the horizontal limb is set truly level; and the plane of the vertical limb should be accurately perpendicular to its axis. To the top of the limb N, N, is attached a bar, which carries two Y's for supporting a telescope, of the same construction as that before described for the Y spirit level; and underneath the telescope is a spirit level, S, S, attached to it at one end by a joint, and at the other end by a capstan-headed screw, as in the Y level. The horizontal axis can be fixed by a clamping screw, and the vertical limb can then be moved through a small space by a slow-motion screw *i*.

* Upon this depends, in a great measure, the perfection of the instrument, as far as the horizontal measurements are concerned; and, when we describe presently the adjustments of the instrument, we shall explain the method of detecting an inaccuracy in the grinding of the axes.

Before commencing observations with this instrument, the following adjustments must be attended to:—

1. Adjustments of the telescope, viz.: the adjustment for parallax; the adjustment for collimation.
2. Adjustment of the horizontal limb, viz.: to set the levels on the horizontal limb to indicate the verticality of the azimuthal axis.
3. Adjustment of the vertical limb, viz.: to set the level beneath the telescope to indicate the horizontality of the line of collimation.

1. *Parallax and Collimation.*—These adjustments have already been described (p. 18) under the head of the Y level.

2. *Adjustment of the Horizontal Limb.*—Set the instrument up as accurately as you can by the eye, by moving the legs of the stand. Tighten the collar, D, by the clamping screw C, and, unclamping the vernier plate, turn it round till the telescope is over two of the parallel plate screws. Bring the bubble of the level, S S, beneath the telescope to the centre of its run by turning the tangent screw *i*. Turn the vernier plate half round, bringing the telescope again over the same pair of the parallel plate screws; and, if the bubble of the level be not still in the centre of its run, bring it back to the centre, half way, by turning the parallel plate screws over which it is placed, and half way by turning the tangent screw *i*. Repeat this operation, till the bubble remains accurately in the centre of its run in both positions of the telescope; and then turning the vernier plate round till the telescope is over the other pair of parallel plate screws, bring the bubble again to the centre of its run by turning these screws. The bubble will now retain its position, while the vernier plate is turned completely round, showing that the internal azimuthal axis, about which it turns, is truly vertical. The bubbles of the levels on the vernier plate being now, therefore, brought to the centres of their tubes, will be adjusted, to show the verticality of the internal azimuthal axis. Now, having clamped the vernier plate, loosen the collar D, by turning back the screw C, and move the whole instrument slowly round upon the external azimuthal axis, and, if the bubble of the level S, S, beneath the telescope, maintains its position during a complete revolution, the external azimuthal axis is *truly parallel* with the internal, and both are vertical at the

same time; but, if the bubble does not maintain its position, it shows that the two parts of the axis have been inaccurately ground, and the fault can only be remedied by the instrument maker.

3. *Adjustment of the Vertical Limb.*—The bubble of the level, s, s, being in the centre of its run, reverse the telescope, end for end, in the Y's, and, if the bubble does not remain in the same position, correct for one half the error by the capstan-headed adjusting screw at one end of the level, and for the other half, by the vertical tangent screw *i*. Repeat the operation till the result is perfectly satisfactory. Next turn the telescope round a little, both to the right and to the left, and if the bubble does not still remain in the centre of its run, the level, s s, must be adjusted laterally by means of the screw at its other end. This adjustment will probably disturb the first, and the whole operation must then be carefully repeated. By means of a small screw, fastening the vernier of the vertical limb to the vernier plate over the compass box, the zero of this vernier may now be set to the zero of the limb, and the vertical limb will be in perfect adjustment.

The second telescope, placed beneath the horizontal limb, serves to detect any accidental derangement of the instrument during an observation, by noting whether it is directed to the same point of a distant object at the end of the observation to which it has been set at the commencement of the observation. This telescope is now very generally omitted, the advantage derived from it being considered to be counterbalanced by the additional length which must in consequence be given to the vertical axis, and which detracts from the compactness and firmness of the instrument.

In the larger instruments the vertical limb admits of an adjustment to make it move accurately in a vertical plane, when the horizontal limb has been first set in perfect adjustment. This adjustment is important, and should be examined with great care; and in the small theodolites, in which the vertical limb is permanently fixed to the horizontal limb, an instrument, which will not bear the test of the examination that we proceed to describe, must be condemned, till set in better adjustment by the maker. The azimuthal axis having been set truly vertical, direct the telescope to some well-defined angle of a building, and, making

the intersection of the wires exactly coincide with this angle, near the ground, elevate the telescope by giving motion to the vertical limb, and, if the adjustment be perfect, the intersection of the cross wires will move accurately along the angle of the building, still continuing in coincidence with it. A still more perfect test will be, to make the intersection of the cross wires coincide with the reflected image of a star in an artificial horizon, and, elevating the telescope, if the adjustment be perfect, the direct image of the star itself will again be bisected by the cross wires.

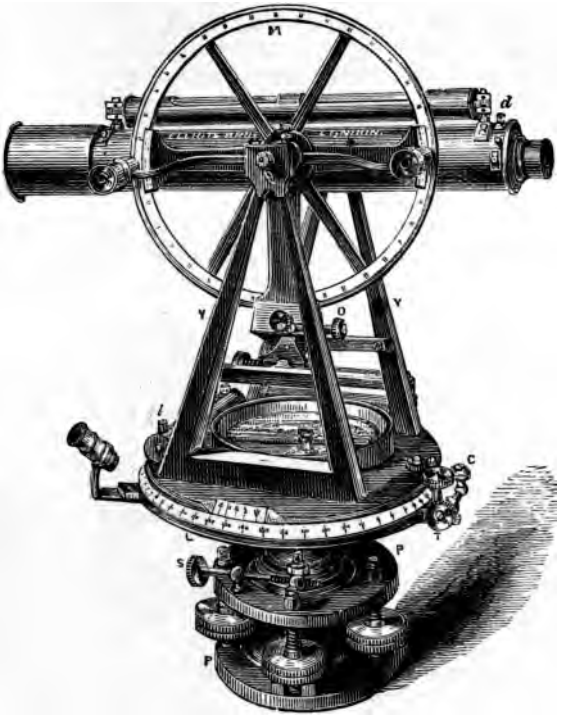
THE TRANSIT THEODOLITE.

The transit theodolite is so called from the telescope being mounted in the same manner as in the transit instrument described hereafter (p. 132). In surveying, the difference of level being determined by the level in the manner already explained, the vertical limb, attached to the telescope of the theodolite, may for most purposes to which it is applied be dispensed with, which makes the instrument both simpler and lighter. When supplied with a vertical limb, that is a complete circle, it becomes at the same time a theodolite, an altitude and azimuth instrument, and a transit instrument, and may be used for astronomical, as well as for terrestrial purposes.

The tripod stand, the parallel plates, and the horizontal graduated limb and vernier plate, differ in no particular from those of the theodolite already described, and, like that, the vernier plate of the transit theodolite carries a compass in its centre between the supports of the telescope, and two spirit levels, *l*, *l*, to serve as a guide for setting the instrument level. As in the ordinary theodolite too, a small microscope for reading the verniers is adapted to slide round the horizontal limb.

The two frames, Y, Y, resting on the vernier plate, carry the bearings for the telescope with its spirit level, and the graduated circle M, called the *vertical* limb with its two verniers, V, and microscopes, for measuring vertical angles, called angles of elevation, or angular altitudes. Upon these bearings, which are usually of the ordinary Y pattern, called therefore the Y's, the horizontal axis of the telescope, with its appendages, is made to rest. The horizontal axis is formed of *two cones, the* larger ends of which are attached to the

middle of the tube of the telescope, while the small ends are ground into two *perfectly equal* cylinders, called *pivots;* and it is these pivots that bear and turn upon the Y's. The common axis of the cylinders and cones must be accurately at right angles to the axis, or rather, to the line of collimation of the telescope, and the adjustment to produce



this is called the *adjustment for azimuth.* This mode of supporting the telescope and vertical limb gives to the transit theodolite its superiority over other modes of construction, as, whenever it is desirable to reverse the ends of the telescope, this is immediately accomplished by merely revolving *it on its* axis, instead of having recourse to the

troublesome operation of opening clips, lifting the telescope out, and replacing it. It also serves to eliminate any error arising from imperfect adjustment, by reversing both the horizontal limb and the telescope, and taking the mean of the two readings thus obtained.

The vertical limb is graduated, from 0° to 90°, through one quadrant, and then again, in the same manner, throughout each of the other quadrants, going round from left to right.

At either end of the spirit level are capstan-headed screws, to adjust it parallel to the optical axis of the telescope, or line of collimation, by tightening the one and loosening the other. The vertical limb is also provided with a tangent screw, o, for slow motion.

The following are the adjustments:—

1. The adjustment for parallax
2. Adjustment of the horizontal limb, and consequent verticality of the azimuthal axis.
3. Adjustment for horizontality of the axis on which the telescope turns.
4. Adjustment for collimation in azimuth.
5. Adjustment for collimation in altitude.

1. *Parallax.*—This adjustment, which has been already described (p. 19), must always be tested by the observer, and corrected, if necessary, as it will differ according as he is long or short sighted. The other adjustments are all made by the maker with great care, for the sake of his own reputation; and in well-constructed instruments derangements are but little likely to occur afterwards, if ordinary care be taken of them; but still they may accidentally occur, and it is desirable, therefore, to examine the instrument, both when new, and from time to time afterwards.

2. *Adjustment of the Horizontal Limb, l.*—This adjustment also has been explained (p. 58).

3. *Horizontality of the Axis on which the Telescope turns.*—This is to be tested by observing a long plumb line; first, making the intersection of the cross wires coincide with this line at the bottom, then, if this intersection moves accurately along the line, as the telescope is raised by turning it on its bearings, this adjustment is perfect; but, if not, the bearing, on the side opposite to that on which the intersection departs from the plumb line, is too high, and should be

lowered, by rubbing the face of the Y with slate pencil and water, or by some equally delicate process. Before proceeding, however, to do this, the next adjustment should be examined, and the test should then be verified, by observing if a star and its image, reflected in an artificial horizon, are both coincident with the intersection of the cross wires, when the telescope is turned upon its bearings.

4. *Adjustment for Collimation in Azimuth.*—Direct the telescope to some distant, small, and well defined, object, and, bringing its centre into exact coincidence with the intersection of the cross wires, clamp the horizontal limb. Lift the telescope off the Y's, and reverse it, so that the bubble will be downwards, and the ends of the horizontal axis, on opposite bearings to what they were before. Now examine if the centre of the object again comes into exact coincidence with the intersection of the cross wires, as the telescope is turned on its bearings; if so, the collimation in azimuth is perfect, and the line of collimation is accurately at right angles to the axis; but if not, correct one half the deviation by turning the two small side screws that adjust the diaphragm, and the other half, by moving the horizontal limb by means of the tangent screw, s. If the half distances have been correctly estimated, the centre of the object will again come into coincidence with the intersection of the cross wires, when the telescope is restored to its first position, and the adjustment will be accomplished; but if not, repeat the operation, until the centre of the object is coincident with the intersection of the cross wires in both positions of the instrument, and the adjustment will be perfected.

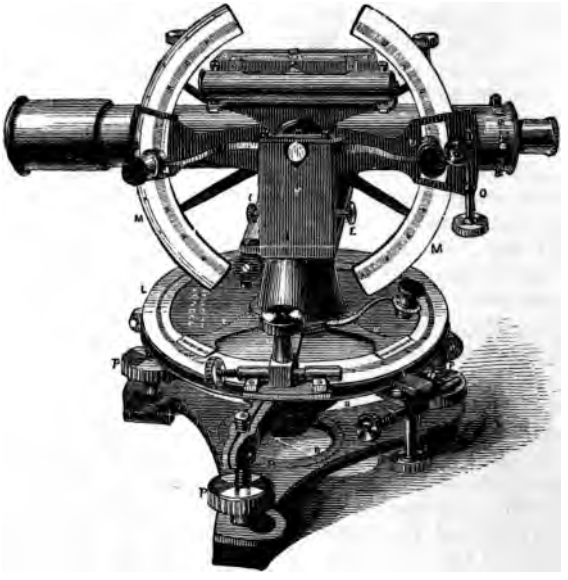
If a star and its reflected image be now observed, as directed for the preceding adjustment, and the test be satisfactorily satisfied, we may consider that both adjustments are perfected.

5. *Adjustment for Collimation in Altitude.*—Point the telescope to a very distant object, or a star, and, bringing the cross wires into coincidence with the object, read off the angle on the vertical circle, as indicated by the verniers. Turn the horizontal line through 180, and again direct the telescope to the same object, and read off the angle on the vertical limb. If the two readings be alike, the adjustment for collimation in altitude is perfect; but, if the readings be different, half their sum will give the true reading. The

verniers should then be adjusted to give the true reading, and, the vertical limb being brought down to zero, the bubble should be brought to the centre of its run: the adjustment will then be complete.

EVEREST'S THEODOLITE.

This instrument has distinctive features, as shown by the figure. The horizontal limb, L, consists of one plate only, on which the degrees are graduated; the verniers, V, are at



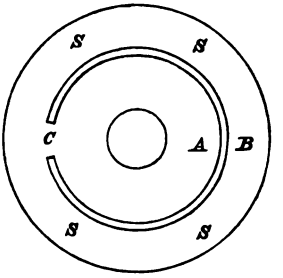
the end of bars radiating from the centre; and another bar carries the clamp, C, and the tangent screw for the verniers. At S are shown the clamp and slow-motion screw of the horizontal limb. The vernier bars are connected with the upper portion of the instrument carrying the telescope, vertical limb, M, &c., and, turning upon the same centre, they show the angle traversed by the telescope.

The tripod support, B, is provided with parallel plate screws, *p*, *p*, *p*. One advantage with this instrument is, that *it may be used* with a three-legged stand, the same as those

already described, or be disengaged from the top of this staff, and placed upon the top of a wall, or in other situations where the ordinary tripod could not be used. It will be seen by the figure, that the telescope and vertical limb are supported in a manner very similar to the transit theodolite, the horizontal axis connected with the telescope resting on two supports, only one of which is seen in the drawing at Y. These are supported by a flat horizontal bar, E, to which is attached a spirit level, only one end of which is seen in the drawing. This level is for adjusting the axis horizontally; and, this being accomplished, the vertical arc, M M, attached to the telescope, moves with it in a vertical plane.

Everest's theodolite is much used in India, but has not met with a very favourable reception in this country. It labours under the disadvantage of not affording means of efficiently testing its adjustments; since the telescope can be turned neither round, nor end for end, as in the ordinary theodolite, nor over on opposite bearings, as in the transit theodolite; neither can it be reversed, like the telescope of the transit theodolite, by turning round on its bearings.

Many persons also dislike the mode of supporting the horizontal limb on three screws only, as these may be shaken by having no opposite bearing to steady them. With the parallel plates, and four screws, each opposite pair bear against each other, and no shake is possible. On the other hand, the advocates of a three-screw bearing object to the parallel plates, and four screws, that, by pressing the upper parallel plate unequally against the azimuthal axis, the centre of this plate, in which the axis turns, may become ovalled. The annexed figure represents a plan for preventing this ovalling, by forming the upper parallel plate of two concentric rings, A and B, joined together at one part only by the bridge C, placed midway between two of the screws S, S. The outer ring will thus admit of a slight bending, and the pressure of the inner ring against the axis being thereby relieved, scarcely any tendency to ovalling can occur.



The most important peculiarity of this theodolite is an adaptation for setting out mechanically, without recourse to measurement or calculation, the surface widths for batter pegs required in all railway earthworks, to indicate the tops of slopes of cuttings, and bottoms of slopes of embankments. The ordinary methods of performing this work involve much tedious calculation, and liability to error, particularly on rough and on sloping ground. By the use of Lister's theodolite this is entirely avoided, and a great saving of time effected, inasmuch as, when the instrument is once fixed in position, the widths may be put out on either side of it as far as the range of the telescope will admit, and almost as quickly as the pegs can be driven. The boundary fence, being parallel with the surface line of the slope, may be set out at the same time. A further advantage possessed by this instrument, consists in its superior adaptation to levelling by vertical angles, particularly where cross sections are required to be taken over very sidling ground. With the ordinary theodolite, the telescope must be reversed, and the vertical angle reset, to take the back sights, and each cross section must be taken separately; but this instrument, being so constructed that the telescope will revolve in any vertical plane, these defects are avoided, and a series of sections may be taken without moving the instrument.

Ordinary theodolites are readily altered to embrace these improvements.

An entirely new form of theodolite has been designed by M. d'Abbadie, and is made in Paris. The telescope is fixed with its line of collimation parallel to the plane of the horizontal circles, which are provided with crossed spirit levels, and divided in the usual way, for the reading of horizontal angles by the aid of a second telescope, fixed to the lower plate. Vertical angles are read off by turning the telescope upon its own line of collimation as an axis. The telescope is provided with a vertical circle, whose plane is fixed truly at right angles to its line of collimation. To measure the vertical angle subtended by two objects—one, suppose the lower one, is observed, as seen reflected in a totally reflecting prism in the telescope tube, whose plane of reflection is parallel to the line of collimation. The vertical circle being then brought to zero and clamped to the telescope,

they are turned round together on the line of collimation, as an axis, until the higher of the two objects is seen reflected in the same prism, the precise position being fixed by cross wires in the field. The vertical angle between the two objects is now read off upon the vertical circle, whose centre is on the line of collimation. This instrument is very original in conception, and is said to work well, and with perfect accuracy. It presents the advantages of not being easily thrown out of adjustment by carriage or rough usage, is light, even when strongly made, and not as costly as the older forms.

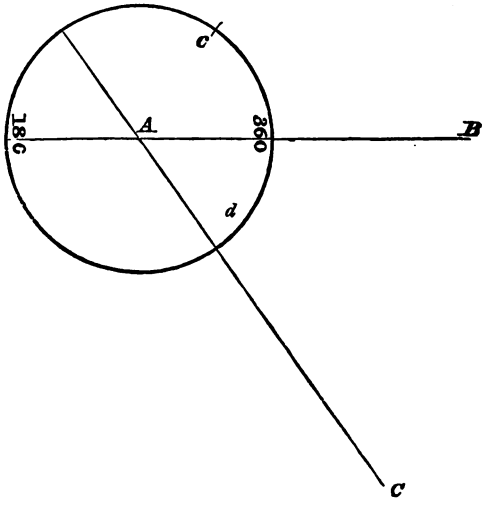
MEASURING ANGLES WITH THE THEODOLITE..

It may be as well to observe to the beginner, that but little anxiety need be felt as to the adjustments of an instrument supplied by a good maker, although the student may make an examination of the value and condition of the instrument, as soon as he feels confident he has mastered the principles and details of its construction. What he has really to apprehend, is the damage the instrument is liable to, when brought into use—and this, not from his own hands, but from those of others, particularly *chainmen*, whose hands it is difficult to keep off the instrument, when his back is turned for a short time. Let him, therefore, be advised never to leave an instrument on the ground, without its being under the care of some person, on whom he can thoroughly depend; for the curiosity of an ignorant man, and his desire to handle that of which he has no conception, are often unrestrainable, where there is, as he thinks, no fear of detection, and have often led to serious consequences. When the day's work is over, restore the instrument to its case, and keep the key: the sense of security thus ensured, more than repays the few minutes of trouble incurred.

In measuring angles with the theodolite, supposing the instrument (p. 61) in adjustment, and secured on its three-legged support, ready for use, the first thing to be done is to plant the instrument somewhat about level, exactly over a station from which observations are to be made, giving the three legs a wide spread, and fixing them as firmly in the ground as circumstances will admit. The tripod is made of such a length, that, when a sufficient spread is given, the height of the eye-piece of the telescope will be most convenient to the

observer. The exact position of the centre of the instrument over the centre of the station is ensured by the plummet and line, that hang from the centre of the instrument, being close over a peg in the ground, or dropping into the hole itself, from which a flag-pole has been removed, to make place for the theodolite. Now set it level, by turning the parallel plate screws, *p*, *p*, until the bubbles of the two spirit levels on the vernier plate keep the centre of their run, whilst the telescope is turned steadily quite round on its centre; and the instrument will be ready for measuring angles.

Let A be the station; and let it be required to measure the angle subtended by B and C. Clamp the zero of the vernier plate to zero, or 360°, on the limb, and make the coincidence perfect by means of the tangent screw T. Examine the zero of the other vernier, and see that it coincides with



180°. Move the instrument bodily round, until the intersection of the wires in the telescope is in contact with the object at B. Clamp the instrument by means of the screw attached to the collar round the axis, and make the *bisection* of the object at B, by the wires, perfect by means of the slow-motion screw S. This exact bisection can only be

secured, when clear and distinct vision has been obtained by means of the milled head in the side of the telescope, for adjusting the object-glass. The line of sight having thus been made to pass from A exactly through zero, or 360° on the limb, and the centre of the object at B, release the vernier plate, by loosening its clamp, and turn it round, until the intersection of the wires is again in contact with the object at C; then tighten the clamp of the vernier plate, and, by means of its tangent screw, T, make perfect the bisection, by the wires, of the object at C. If there is any considerable difference between the distances of B and C from A, the milled head of the telescope will have again to be turned, to ensure distinct vision. *The angle is now measured*, and the measurement is to be read off from *both* verniers, and the mean of the readings taken: thus let the fore vernier pointing to C read 62° 37′, and the back vernier show 36′ 30″ beyond a degree; then the mean of the minutes and seconds will be 36′ 45″, and the corrected measure of the angle will be 62° 36′ 45″.

In ordinary cases, with a 6-inch theodolite, the above measurement of an angle, read off with *both* verniers, will be found sufficiently accurate; but, where a considerable area is triangulated, or where distant observations are taken from a base line, as well as in traverses of several miles circuit, the angles should be *repeated*, and the mean of all the observations taken as the real measure.

The operation of repeating an angle is performed as follows:—Having taken the first measurement in the manner explained above, loosen the clamp of the lower plate, or horizontal limb, turn the theodolite bodily round, until the telescope is directed upon B, and, again clamping the instrument, perfect the bisection of the object by the cross wires, by means of the slow-motion screw S. The index of the vernier, together with the coincident division on the limb, will thus have been brought from *d* to the previous position of the zero, or division marked 360°, while this will have been carried through an equal arc to *c*. Now release the upper, or vernier plate; turn it until the telescope is directed upon C; clamp it again; and perfect the bisection by means of the tangent screw T. The means of the readings, indicated by the *two* verniers, will now denote the magnitude of an angle twice as large as B A C, and half the amount

may generally be taken as a very accurate measurement of the angle. Should this measurement differ considerably, as half a minute or more, from that first obtained by single observation, the operation may again be repeated, and one-third of the amount, indicated by the readings of the verniers, be taken for the corrected magnitude of the angle.

RANGING LINES WITH THE THEODOLITE.

The theodolite is used, in engineering field-work, for ranging long lines, to form a base line for a system of triangulation, or for setting out a line of railway or canal. This is performed by means of a series of back and fore sights, taken at prominent stations along the line; and, as the back and fore sights, at each station, must be taken without the slightest variation in the position of the vernier plate upon the horizontal limb, this plate should be firmly clamped to the limb, and remain so throughout the whole operation, the indices of the verniers being fixed at zero, or 360°, and 180°, or any two equally marked divisions, and examined at each step, to see that the coincidence remains perfect. After having examined the adjustments, and clamped together the vernier plate and horizontal limb, as above directed, plant the instrument, by means of the plummet and line, exactly over a point selected for the first station, through which the line is to be ranged, and level it by means of the parallel-plate screws. The pole, set up at the place selected for the starting-point, or commencement of the base line, will here form the back object. Direct the telescope to a point on this pole as near the ground as possible; clamp the instrument, and perfect the bisection of the object by the cross wires, by means of the slow-motion screw. As many ranging rods as may be desirable may now be set out, in the prolongation of the line of collimation of the telescope, between the starting-point and the station. This being done, examine the verniers to see that they have not moved upon the limb, and, if the result be satisfactory, reverse the telescope, and again set out ranging rods as far as it commands the ground, in every case directing the intersection of the cross wires upon a point as low down upon the rod as possible. Now direct the telescope to the next commanding situation on the base, and set up a pole there, to mark the spot for the next station. Move on to this station,

and proceed in the same way, and so from station to station, until the entire line is set out.

In the performance of this work the superiority of the transit theodolite is immediately perceived, the reversal of the telescope being accomplished by the simple operation of revolving it on its axis. With the ordinary theodolite, the reversal must be performed by opening the clips, lifting out the telescope, turning it round, and resetting it again. The Everest theodolite, in which the telescope can only be reversed by turning it round in azimuth through 180°, is still less adapted for this purpose.

TRAVERSING WITH THE THEODOLITE.

In the conduct of an extensive survey, the two principal desiderata are accuracy and dispatch, neither of which should be unduly sacrificed to the other. To obtain both these ends, the principal points of the survey should be determined by a system of triangles, proceeding from an accurately-measured base of considerable length. The angles of these triangles should be observed with a large and perfect theodolite, constructed for the purpose, or with an altitude and azimuth instrument; and numerous corrections should be applied, for the spherical form of the earth, the refraction of the atmosphere, the errors due to the imperfect graduation of the instrument, &c.

The boundaries of the entire country to be surveyed being thus determined with the greatest possible accuracy, and a series of stations laid down throughout, the spaces included between these stations may be subdivided into spaces of smaller extent, the boundaries of which may be surveyed with considerable dispatch by means of the chain, and a portable theodolite, such as we have been describing above; and lastly, the details of the country within these spaces may be sketched with still greater rapidity by means of the prismatic compass.

The boundaries of the spaces to be surveyed by the chain and small theodolite should not exceed three or four miles in extent, and the following is the manner of proceeding.

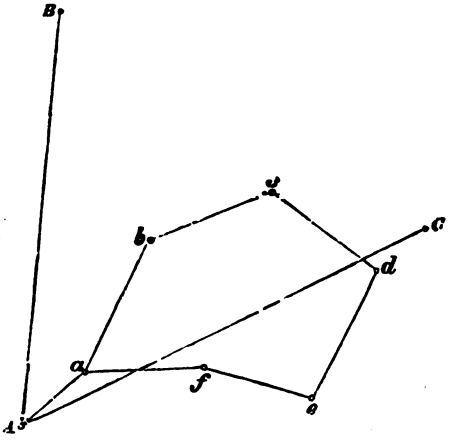
Let *a*, *b*, *c*, *d*, *e*, *f*, represent the boundary to be surveyed, and let A, B, and C, be three stations, that have been accurately laid down by the previous triangulation, of which both B and C *can be seen* from A, and A can be seen from C. First *measure with the* chain the lengths of the several lines *a b*,

b c, *c d*, &c., taking offsets to all remarkable points on either side of these lines, in the usual manner, and driving pickets at *a*, *b*, *c*, &c. Measure also the distance from A to *a*, and from *d* to C. These measurements having been made, set up the theodolite at A, level it, and clamp the vernier plate to the lower plate of the horizontal limb, at zero, or so that the readings of the two verniers may be 360° and 180° respectively, this adjustment being perfected by the slow-motion screw T. Next move the whole instrument round upon the azimuthal axis, till the object B is accurately bisected by the cross wires, clamp it firmly in this position by the screw, tightening the collar, and enter in the field book the reading of the compass. Now release the vernier plate, and turning it round, bisect the object C, by the cross wires, and enter the readings of both verniers in the field book. Observing, in like manner, the bearings of any other remarkable objects, and, entering the readings in the same way, direct the telescope lastly to *a*, at which station an assistant must be placed, with a staff held upon the picket there driven into the ground, and, entering the reading of the vernier as before, clamp the vernier plate carefully, and remove the instrument to *a*. Level the instrument at *a*, unclamp the collar, and, turning round the whole instrument upon the azimuthal axis, direct the telescope to the last station A, tighten the collar again, and perfect the adjustment, if necessary, by the slow-motion screw S. Now release the vernier plate, and, bringing it back to zero, if the reading of the compass be the same* as the reading previously entered in the field book, we assume our work, as far as it has gone, to be correct; but, if not, we must go back to A, and go over the work again.† Next, with the lower plate still clamped, and the vernier plate released, enter the readings

* If the horizontal limb be figured throughout one semicircle up to 180°, and then, commencing again from 0°, be figured up to 180 at the original starting-point, the readings of the compass will be the same, as stated in the text; but if, as in the transit theodolite, the horizontal limb be figured all round, from 0 up to 360°, the readings would differ by 180°. To make the readings the same in this case, the observations at the second station should be made with the telescope reversed, by revolving it on its bearings.

† If the same result be again arrived at, we may presume that the compass is acted on by some local attraction, and proceed with the work; and the accuracy of this presumption will be further tested as we go on.

when the telescope is directed to the several remarkable points visible from *a*, and lastly direct the telescope to the next forward station *b*, as before, clamping the vernier plate at each observation, and perfecting the adjustment with the tangent screw. In the same manner, proceed from *b* to *c*, *c* to *d*, and *d* to C; and, having directed the telescope at C to the last back station *d*, and released the vernier plate, direct the telescope to A; and, if all the angles have been correctly measured up to this time, the readings of the verniers will now be the same as when the telescope was directed to C from the point A. If then we have not been able to make all the compass readings agree at the previous stations, after going twice over the work at such stations, we may now consider that our work was correct, and that the errors in the compass reading arose from some local attraction, or extraordinary variation of the needle. This verification of the work at C, is called *closing the work.*



We now come back again to *d*, and proceed from *d* to *e*, and so on, as before, till we come to some other station, which has been observed, either from A or C, and which we again close upon, and at last arriving at *f*, if the readings agree within a minute or two with the readings for *f*, previously observed at *a*, the whole work may be considered to have been performed with a sufficient degree of accuracy; but, if the error amount to more than a minute or two, we must proceed back again from *f* to *e*, and so on till we find out the station at which the error has occurred.

If the ground along any of the lines a b, b c, &c., rise or *fall, suppose for instance*, along b c, then we must direct the

telescope from *b*, so as to make the cross wires bisect, upon the staff, held upon the picket at *c*, a point at the same distance from the ground as the centre of the telescope, and then upon one side of the vertical limb is pointed out the number of links to be deducted for each chain, from the measured distance *b c*, to reduce it to the required horizontal distance This reduction is then to be entered in the field book.*

PLOTTING THE SURVEY.

Having now explained the instruments to be used for the measurement of both linear and angular distances, it remains to consider the means to be used for laying down on paper the results obtained from them. This is called *plotting the survey*. The instruments to be used in plotting are described fully in Vol. I. Part I., on Drawing Instruments.

If the survey has been made entirely with the chain, the chain lines will all be sides of triangles, which have been measured, and the survey is to be plotted by laying down their lengths with the ordinary or beam compasses, according as they are short or long; and the offsets from them may be pricked off by means of a plotting and offset scale.

Care must be taken that the sheet of paper is large enough to contain the work, and, also, to lay down the first line in such a manner that the whole of the survey shall come conveniently into the paper. For this purpose a plot of the outline, to a small scale, should first be made, or a rough sketch made on the ground will frequently suffice.

Having selected the position for the first line, and laid it down of its proper length, the lengths of the two other sides of the triangle, of which it forms the base, are to be taken with the compasses; arcs with these distances being struck from either end of the base, the intersection of these arcs will give the vertex of the first triangle to be laid down; and the sides must then be drawn from the vertex to either end of the base. Proceeding in a similar manner with the other measured lines, all the triangles will be filled in, and the detail may then be set off from the principal lines thus drawn.

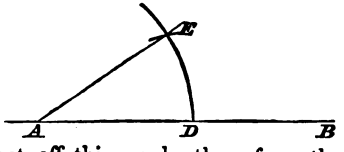
When the theodolite has been used, and it is desired to protract the angles observed, a circular protractor of some

* *The method* of surveying with the chain and theodolite, *explained above, is* called surveying by traverse.

kind must be used. The different forms of this instrument are described in "Mathematical Instruments," Part I., and their respective advantages pointed out.

In plotting a traverse, unless great care be used, both as to the lengths of the lines, and their angular bearings, the work will not close accurately; and, before protractors were so perfectly constructed as at present, either the method of northings and southings, eastings and westings, hereafter described, had to be employed, or the angles had to be protracted by chords.

To *protract by chords*, find in a table of sines, the sine of half the angle to be protracted, and double it. The number thus found, multiplied into a convenient length, will give the chord of the angle to a radius of the assumed length, and an arc being described with this radius, the chord, laid in it, will subtend at the centre the required angle. Thus, to set off an angle of 34°. In the table of sines, the sine of $\frac{34}{2}$°, or 17°, is ·29237, and, multiplying this by 200, we have 58·5, for the chord of 34° to radius 100. To set off this angle, then, from the point A of the line A B; with radius 100 describe the arc D E, intersecting A B in D, and with radius 58·5, from centre D cut the arc D E in E: then D E will be the chord, and D A E will be the required angle, of 34°. In practice, it is not necessary to draw a long arc D E, but only to mark the position of D, and describe two small arcs at E with radii A D, and D E, respectively.



The process of laying down angles by the system of chords, just explained, gives results far more accurate than can be obtained by any other means, since they can be protracted by the beam compass with radii as large as we please. This mode is necessarily used, therefore, for laying down the principal angles of a trigonometrical survey on a large scale. In fact, for all large triangles, protracting by chords is the only trustworthy method, and should always be resorted to when the sides of the triangles exceed two feet in length.

The method of northings, southings, eastings, and westings, is another most admirable system of plotting, especially useful

when it is a principal point to obtain the area of an estate or parish, &c. The first step is to procure, or form, a table of northings, southings, eastings, and westings*, for all angles made with a meridian line, and for all distances from 1 to 100. These distances may be either links, feet, chains, or estimated in any denomination whatever, and the corresponding northings, southings, eastings, and westings, will be in the same denomination. This table is, in fact, nothing more than the products of the sines and cosines of the angles, made with the meridian line, multiplied by the several distances, and the following is the method of using it. Take out from this table the northings, southings, eastings, and westings, made on each of the lines of the survey, the line from which the angles have been measured being for this purpose assumed as the meridian, no matter in what direction it may lie, and place them in a table, which we may call a traverse table, in four separate columns, being the third, fourth, fifth, and sixth columns of the table†, headed N., S., E., and W. respectively. Add up these several columns, and, if the work is so far correct, the sum of the northings will equal the sum of the southings, and the sum of the eastings will equal the sum of the westings. Then, in two additional columns, enter the whole quantities of northing and easting, made at the termination of each of the several bounding lines of the survey. These quantities will be determined by putting zero for the greatest southing, and adding, or subtracting, the northing, or southing, made on each particular line, to, or from, the whole quantity of northing, made at the beginning of this line, or at the termination of the preceding line; and again, by putting zero for the greatest westing, and adding, or subtracting, the easting, or westing, made on each line, to, or from, the whole quantity of easting at the beginning of the line.

The preparatory table having been formed, the plot may be laid down with great accuracy; and, for an extensive traverse of a mile or two across, no method will give better results, although it is a little tedious. It is, however, applied with greater facility, if a rough sketch of the work be first plotted as a guide. This rough sketch will enable a point on

* This table is the same as the table given in books on navigation, and then called a table of latitude and departure.

† *The first and second columns of the traverse table contain the courses and distances.*

the paper to be selected for the starting-point, through which a line should be drawn to represent a meridian. The northings and southings may be marked off on this line, measuring each distance, taken from columns 3 and 4, from the point last found, and proceeding upwards for the northings, and downwards for the southings. The accuracy of the divisions may then be checked, by measuring their respective distances from the lowest division thus obtained, as these distances ought to agree with the total northings in column 7. Lines, perpendicular to the meridian, are then to be drawn through the divisions thus found, and on these perpendiculars are to be set off the eastings and westings. Mark them off, first, on one of the east and west lines just drawn, measuring each distance, taken from columns 5 and 6, from the point last found, to the right for eastings, and to the left for westings; then, opposite the division thus found, upon their proper perpendiculars to the meridian, will be found the correct position for plotting the points of the survey. Much labour may be saved by making the plot on paper previously ruled with two sets of equidistant parallel lines, at right angles to each other, the distances apart of the lines according with the scale to which the plot is to be made.

To compute the Area of the Plot.—Rule six additional columns. In the first of these, or ninth column of the traverse table, set the sums of the total northings, and in the tenth, the sums of the total eastings, at the beginning and end of each line in the survey; which sums will be found by adding together each pair of succeeding numbers in the two preceding columns. In the eleventh column set the products of the eastings, made on the respective lines of the survey, found in the fifth column, multiplied by the corresponding sums of the total northings, in the ninth column; and in the twelfth column set the products of the westings, found in the sixth column, and the corresponding sums of the total northings in the ninth column. Sum up the eleventh and twelfth columns, and the difference of the totals thus found will be twice the area of the plot. Again, in the thirteenth and fourteenth columns, set the products of the northings and southings in the third and fourth columns, multiplied by the corresponding sums of the total eastings in the tenth column, and the difference of the totals of the thirteenth and fourteenth columns will again be twice the area of the plot. If it agree nearly with the double area before found, it shows

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Courses.	Distances.	Northings.	Southings.	Eastings.	Westings.	Total Northings.	Total Eastings.	Sums of Total Northings.	Sums of Total Eastings.	East Products.	West Products.	North Products.	South Products.
	ch. lin.	ch. lin.	ch. lin.	ch. lin.	ch. lin.	ch. lin.	ch. lin.	ch. lin.	ch. lin.	acres.	acres.	acres.	
	0 00	...	...	...	...	13 76	0 84						
N. 31° 20′ E.	10 16	8 68	...	5 29	...	22 44	6 13	36 20	6 97	19·14980	...	6·04996	
N. 87 15 E.	9 23	0 44	..	9 22	...	22 88	15 35	45 32	21 48	41·78504	...	·94512	
S. 14 00 E.	6 66	...	6 46	1 61	...	16 42	16 96	39 30	32 31	6·32730	...	...	20·87226
S. 12 25 W.	11 00	...	10 74	...	2 37	5 68	14 59	22 10	31 55	...	5·23770	...	33·88470
S. 64 10 W.	13 4	...	5 68	...	11 74	0 00	2 85	5 68	17 44	...	6·66832	...	9·90592
N. 44 17 W.	4 9	2 93	...	...	2 87	2 93	0 00	2 93	2 85	...	·84091	·83505	
N. 4 28 E.	10 86	10 83	...	0 84	...	13 76	0 84	16 69	0 84	1·40196	...	·90972	
		22 88	22 88	16 96	16 98					68·66410	12·74693	8·73935	64·66288
										12·74693			8·73985
										55·91717			55·92303
													55·91717
												4)	111·84020
											Acres		27·96005
													4
											Roods.....		3·84020
													40
											Perches		33·60800

the calculations to have been correctly performed. (We give an example in the preceding page.)

The near agreements of the sums of the third and fourth, and of the fifth and sixth columns, is a test of the accuracy of the survey; in columns 7 and 8, we have the distances to be set off by the plotting scale; in column 9, we have the multipliers, by which the east and west products, in columns 11 and 12, are found; and in column 10, we have the multipliers, for finding the north and south products, in columns 13 and 14. The difference of the sums of the eleventh and twelfth columns gives double the area; the difference of the sums of the thirteenth and fourteenth gives again double the area; and, taking the mean of these results, by adding them together, and dividing by 4, we obtain the area, most probably to within a quarter of a perch, since the two double areas differ by less than a perch.

In exploring a wild country, of which we have only a very imperfect map, as a guide, or perhaps none at all, the computations of the northings, southings, eastings, and westings, become indispensable, that the observer may determine his position, in the same way as the sailor, who makes use of the same distances under the names of latitude and departure.

CHAPTER IV.

INSTRUMENTS FOR DETERMINING AT ONCE THE DISTANCE OF AN OBSERVED OBJECT.

THE STADIUM FOR MEASURING DISTANCES IN RIFLE PRACTICE.

THIS instrument, used throughout the army for the rapid measurement of distances with sufficient accuracy for the purpose of rifle-practice, was originally designed by Major A. C. Cooke, R.E., and introduced in its present form by Major-General Hay, the Inspector-General of Musketry.

A B C (Fig. 1), represents the stadium.
A is a side sight.
B „ front ditto.
C „ back ditto.
H „ movable ditto.
D E is a tape or chain.
D H is the distance to be measured.

The principle of the stadium depends on the well-known

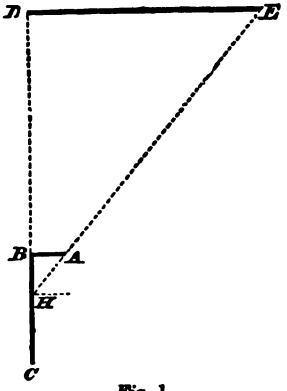


Fig. 1.

mathematical proposition, that in similar triangles the similar sides are proportional. In the two triangles E D H, A H B, the right angle E D H is equal to the right angle A B H, and the angle E H D is common to both triangles: the two triangles are, therefore, similar, and their sides proportional: H D has therefore the same proportion to H B, that E D has to A B. The length of D E is fixed, and that of B A being also fixed, their proportion is known: suppose it to be as 120 to 1, then D H will also be 120 times B H.

To construct the stadium, then, it is only necessary to fix on a suitable proportion between D E and B A, say 120 to 1, and then to mark the divisions on B C 120 times their real length; that is, if B H is really 12 inches, it is marked 120 feet, and indicates the distance from D to H. In fact, every inch on B H corresponds to a distance of 10 feet and is marked accordingly.

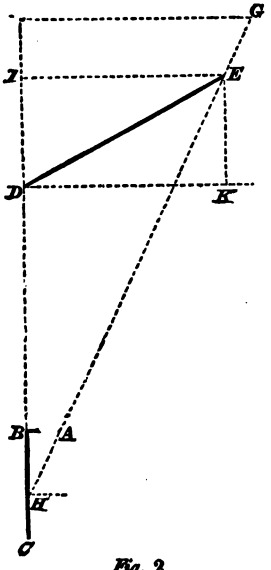


Fig. 2.

The absolute correctness of the result obtained depends upon the two triangles A B H, E D H being strictly similar, and this again depends upon the tape, D E, being held exactly at right angles to D H; for if it is not, the angle E D H will not be equal to the angle A B H. It is desirable, therefore, to ascertain what error in the determination of the distance may be expected from this cause.

Suppose D E to be held as much out of the perpendicular as is shown in Fig. 2. The real distance D H remaining the same, the distance indicated, by B H, on the stadium, is evidently very different in Fig. 2, to what it is in Fig. 1. Let F G be an imaginary tape held at right angles to F H, the end of which, G, falls on the prolongation of H E; it is evident that the distance indicated on the stadium will be that of F H, and the amount of error, or the difference between the real and the indicated distance, will be F D.

Put F D $= x =$ error to be determined.

E K $= e =$ I D $=$ the number of yards that the man at the end, E, of the tape is out of the perpendicular.

H F $= d =$ apparent distance;

D E $= t =$ F G $=$ length of tape, in yards;

then $\text{IH} = \text{HF}\,\frac{\text{IE}}{\text{FG}} = d\,\frac{\sqrt{t^2-e^2}}{t}$;

$\text{HD} = \text{IH} - \text{ID} = d\,\frac{\sqrt{t^2-e^2}}{t} - e$; when the angle E D H is greater than a right angle;*

$= \text{IH} + \text{HD} = d\,\frac{\sqrt{t^2-e^2}}{t} + e$; when the angle E D H is less than a right angle.†

and $x = \text{HD} - \text{HF} = -d\left(1 - \frac{\sqrt{t^2-e^2}}{t}\right) - e$; when the angle E D H is greater than a right angle.*

$= -d\left(1 - \frac{\sqrt{t^2-e^2}}{t}\right) + e$; when the angle E D H is less than a right angle.†

By substituting values of t, e, and d, in these general equations, the amount of error in the distance indicated on the stadium can be calculated under all conditions.

* In this case the correction is always negative, or to be subtracted from the distance indicated.

† In this case e is sometimes greater than $d\left(\frac{\sqrt{t^2-e^2}}{t}\right)$, and sometimes less: in the former case the correction is positive, or to be added; in the latter negative, or to be subtracted.

The following tables have been calculated from these equations :—

TABLES *showing the error arising in the indications of the stadium when the tape or chain is not held at right angles to the line to be measured.*

t = 40 = length of tape, in yards.
e = number of yards that the end of the tape or chain is out of the perpendicular.
d = distance indicated by the stadium, in yards.
x = error in distance indicated: when the sign + is annexed, the value of x is to be added to the reading of the stadium, and when the sign — is annexed, it is to be subtracted.

Value of d, in yards.	The Angle E D H less than a right angle.							The Angle E D H greater than a right angle.						
	$e=1$	$e=3$	$e=5$	$e=7$	$e=9$	$e=11$	$e=15$	$e=1$	$e=3$	$e=5$	$e=7$	$e=9$	$e=11$	$e=15$
	Values of x, in yards.							Values of x, in yards.						
100	+1	+2¾	+4¼	+5½	+6½	+7¼	+7¾	—1	—3¼	—5¾	—8½	—11½	—14¾	—22¼
200	+½	+2½	+3½	+4	+3¾	+3¼	+½	—1½	—3½	—6½	—10	—14¼	—18¼	—29½
300	+½	+2¼	+2¾	+2½	+1¼	—½	—7	—1⅙	—3¾	—7¼	—11½	—16¾	—22½	—37
400	+½	+1¾	+1¾	+½	—1¼	—4½	—14¼	—1⅙	—4¼	—8¼	—13¼	—19¼	—26½	—44¼
500	+½	+1½	+1	—¾	—3¾	—8¼	—21½	—1½	—4½	—9	—14¾	—21¾	—30¼	—51½
600	+¼	+1¼	+¼	—2¼	—6½	—12	—28¾	—1¼	—4¾	—9¾	—16¼	—24½	—34	—58¾
700	+¼	+1	—½	—3¾	—9	—16	—36	—1¼	—5	—10½	—17¾	—27	—38	—66
800	+¼	+¾	—1¼	—5¼	—11½	—19¾	—43½	—1¼	—5¼	—11¼	—19¼	—29½	—41¾	—73½
900	+⅛	+½	—2	—7	—14	—23½	—50¾	—1¼	—5½	—12	—21	—32	—45½	—80¾
1000	+⅛	+¼	—2¾	—8½	—16¾	—27½	—58	—1⅛	—5¾	—12¾	—22½	—34¾	—49½	—88

The indications of the stadium are also liable to error from a second cause, namely, the tape not being held horizontal. In this case the effect will be the same as if the tape were too short. Using the same notation as before, e representing the difference of level between the two ends of the tape, the equation, obtained from Fig. 3, will be

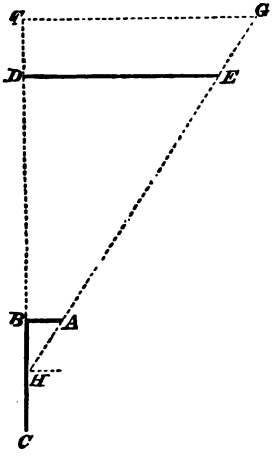


Fig. 3.

$$x = -d\left(1 - \frac{\sqrt{t^2 - e^2}}{t}\right)^*$$

The following table has been calculated from this equation :—

TABLE *showing the error in the indications of the stadium when the two ends of the tape or chain are not horizontal.*

$t = 40$ = length of tape, in yards.
e = difference of level between the two ends of the tape or chain.
d = distance indicated by the stadium, in yards.
x = error in distance indicated, to be subtracted from the reading of the stadium.

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* This correction is always negative. If, however, the instrument instead *of being used with* B A horizontal, were held with B A parallel *to the tape, no error could* arise from want of horizontality in the tape.

Value of d, in yards.	$e=1$	$e=3$	$e=5$	$e=7$	$e=9$	$e=11$	$e=15$
	Value of x, in yards.						
100	—	$\frac{1}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{3}{4}$	$7\frac{1}{4}$
200	$\frac{1}{8}$	$\frac{1}{2}$	$1\frac{1}{2}$	3	$5\frac{1}{4}$	$7\frac{3}{4}$	$14\frac{1}{2}$
300	$\frac{1}{8}$	$\frac{3}{4}$	$2\frac{1}{4}$	$4\frac{1}{2}$	$7\frac{3}{4}$	$11\frac{1}{2}$	22
400	$\frac{1}{8}$	$1\frac{1}{4}$	$3\frac{1}{4}$	$6\frac{1}{4}$	$10\frac{1}{4}$	$15\frac{1}{2}$	$29\frac{1}{4}$
500	$\frac{1}{8}$	$1\frac{1}{2}$	4	$7\frac{3}{4}$	$12\frac{3}{4}$	$19\frac{1}{4}$	$36\frac{1}{2}$
600	$\frac{1}{4}$	$1\frac{3}{4}$	$4\frac{3}{4}$	$9\frac{1}{4}$	$15\frac{1}{2}$	23	$43\frac{3}{4}$
700	$\frac{1}{4}$	2	$5\frac{1}{2}$	$10\frac{3}{4}$	18	27	51
800	$\frac{1}{4}$	$2\frac{1}{4}$	$6\frac{1}{4}$	$12\frac{1}{4}$	$20\frac{1}{2}$	$30\frac{3}{4}$	$58\frac{1}{2}$
900	$\frac{1}{4}$	$2\frac{1}{2}$	7	14	23	$34\frac{1}{2}$	$65\frac{3}{4}$
1000	$\frac{3}{8}$	$2\frac{3}{4}$	$7\frac{3}{4}$	$15\frac{1}{2}$	$25\frac{3}{4}$	$38\frac{1}{2}$	73

EDGEWORTH'S STADIOMETER OR SURVEYING INSTRUMENT.

This instrument is mounted on an ordinary tripod stand, and consists of a set of parallel plates and screws, marked G′ (Fig. 1); a round disc, marked A, on which a sheet of paper can be fastened by means of the little clips C C′; a telescope M B, fitted on an arc O, which has a vertical motion in a frame P G; and this frame P G has a circular and independent motion round the disc or table A. There is a scale D D′, fastened in the frame P G, the centre of which corresponds with the centre of the instrument, and which is graduated to the scale to which the surveyor wishes to have his survey plotted. The telescope, M B, is fitted with a diaphragm, with two horizontal hairs, distant from one another a hundredth part of the focal length of the object-glass. From this proportion it follows that, when an ordinary levelling staff is held on any distant point, and the telescope brought to bear upon it, if the readings, in feet and decimals of a foot, of the intersections of the hairs on the staff be observed, their difference, multiplied by a hundred, gives the true distance, in feet, of the staff from the instrument. The hairs can be adjusted by means of the screws R and R′, from observations on a staff at a known distance.

We have thus a simple and speedy method of measuring *the distances* around the instrument.

Some correction, however, of this method must be made in obtaining distances in precipitous grounds: in such cases it is necessary that the staff should be held at right angles to the

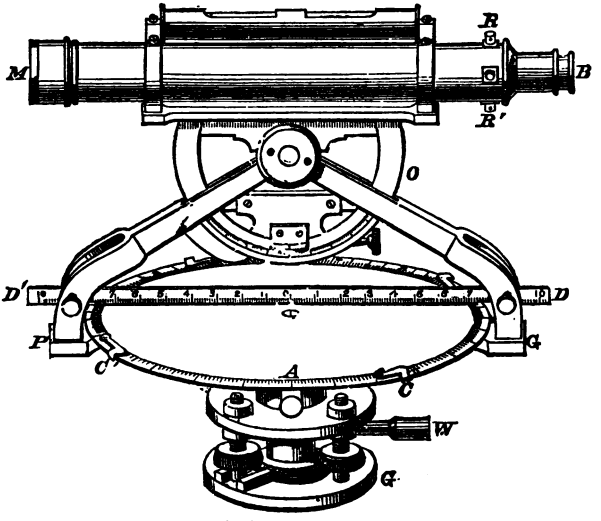

Fig. 1. (*About one-fourth full-size.*)

axis of the telescope observing it, and not upright, as the staff man would feel naturally disposed to hold it. Thus the operation of determining a distance in precipitous ground is as follows:—

The instrument is at the point A (Fig. 2), and the horizontal distance A F is required to be known. The man holding the staff sights the instrument through a hole, bored square through the staff at C, or other device, so that when he sights the instrument, the staff must necessarily be at right angles to the line of sight. He then signals to the observer, who takes the readings at E and D, the difference of which multiplied by 100, is the true distance from C to A. This, corrected for the hypothenusal excess, gives the horizontal distance A F. It is to be observed that these corrections are only necessary in precipitous places; and that, as a general rule, when the obliquity of the ground is less than 15°, there is no appreciable error introduced by taking the readings of the staff held in the ordinary way, and no necessity for any

correction on account of the excess of hypothenusal over base length.

The correction for hypothenusal over base distances is marked on the limb o, which is moved by a thumb-screw, as in a theodolite.

The operation of surveying with this instrument is as follows:—The surveyor first sets out his base lines and lines of triangulation, which he can do with the telescope. The base line should, of course, be chained, if it is at all an extensive survey, and stakes driven at suitable and known points. The instrument is then by means of a

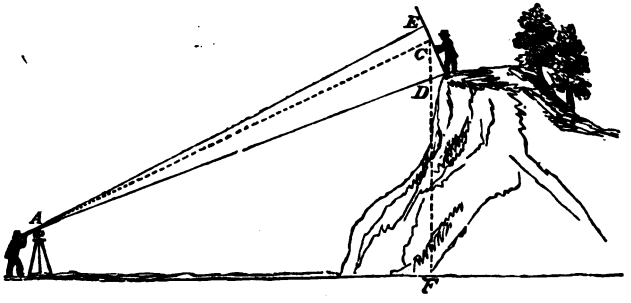

Fig. 2.

plumb bob, set vertically over any of these points. A sheet of paper is put on the table, and a line to correspond with the base line of the survey marked on the sheet. This line, by means of the telescope, is brought to coincide in direction with the base line, and the table is then clamped by the screw W. The staff men now take their staves to the various salient points in the surrounding ground, such as A, B, C, D. (Fig. 3.)

The distances of these points from the instrument are measured by means of the hairs in the eye-piece of the telescope; and their directions correspond with the directions of the telescope. When, then, the distances, corrected, if necessary, for hypothenusal excess, are taken along the scale D, D′, and marked on the paper, the points thus shown are in their true positions on the plan; and a line, drawn through *these points* with a pencil, completes the plotting of the *rough sketch.* When the surrounding fences, houses, roads,

ponds, &c., have been observed, the instrument is moved on to the next station, and another paper put on, a note having been previously made on the old paper of what portion of the survey it referred to. The surveyor, in the evening, transfers all these detached portions of the survey to his office plan, by means of tracing, pricking through, or other draughtsman's device.

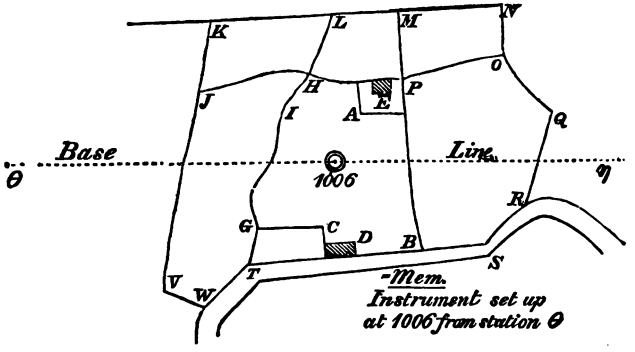

Fig. 3.

The advantages claimed by this system over the ordinary methods of chaining distances, and taking offsets, are these :—

1. A far increased rate of speed in the field.

2. The reduction to the minimum of office operations, which are at present so tedious, and occupy nearly as much time as the field work.

3. In places where waters, or inaccessible heights intervene, and where one cannot chain, but must triangulate, this method of obtaining distances, and their position, is obviously most advantageous.

4. The physical exertion of the surveyor is considerably reduced; for, instead of following the chainman, he has only to stay by his instrument.

5. The chances of error are reduced, because an error in one observation is confined to that one operation, and not brought forward as in the ordinary method; and the surveyor has an opportunity of comparing his plotted survey with the ground.

6. The levels of the ground, or contour lines, can be ascertained *during the operations*, and marked on the survey.

It is to be observed, that the scale D, D′ is capable of being

changed for any scale that the surveyor may wish to use; and that the plate A comes off; which admits of the instrument being fitted into a very handy flat box. The plate A is eight inches in diameter, and would thus command, to a scale of 200 feet to the inch, 800 feet on both sides of the base line.

Moreover, the disc is divided into degrees, and may be used, as in a theolodite, for taking horizontal angles. A compass, also, can be attached to this instrument when necessary.

This instrument has been used with considerable success in several railway surveys, for which it is particularly suited.

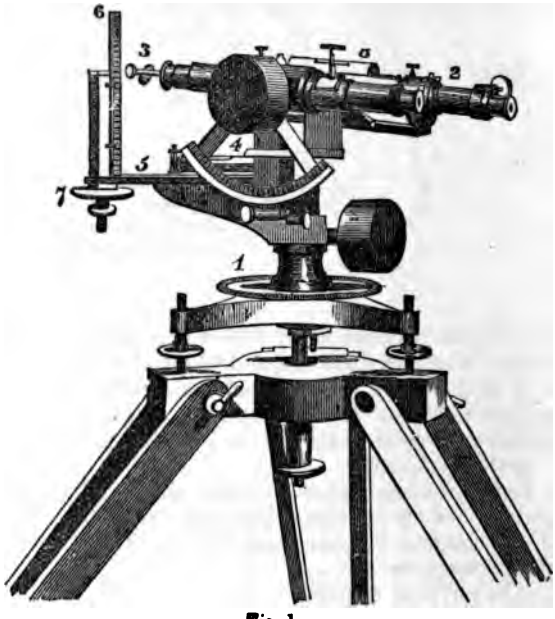

Fig. 1.

THE OMNIMETER.

An instrument called an omnimeter has recently been invented by M. Eckhold, a German engineer. It is intended, like the stadiometer just described, to measure base lines and distances, without chaining, and also differences of altitude and angles. It is, however, a far more perfect instru-

ment than the stadiometer; and we are assured by Messrs. Elliott, that it gives wonderfully accurate results.

The instrument, represented in Fig. 1, on the opposite page, consists of the following parts:—

A graduated limb (1), reading by means of a vernier to ten seconds, for the measurement of horizontal angles;

A good telescope (), revolving in a plane perpendicular to the limb;

A powerful microscope (3), closely united to the telescope;

A highly sensitive level (4) lying upon a rule (5), which has a fixed length (of twenty centimètres, for example);

A scale (6), fixed vertically at the extremity of the said rule, in the plane of the optical axis of the microscope, and divided into half millimètres, the millimètres only being indicated by figures from 1 to 100;

A micrometrical screw (7), attached to the base of the scale, and giving the correct reading of the scale to the $\frac{2}{10000}$ of a millimètre, denoted on the graduated circle of the screw;

A second extremely sensitive level (8), capable of being applied to the telescope, and of determining, in case of need, its horizontality;

Further, of all the necessary screws, keys, and other matters, required to secure the efficient working of the instrument.

As the necessary complement of the omnimeter, there is a staff, Fig. 2, not divided, having an invariable length (as, for example, three mètres), defined on it by two white lines on a black ground, one at the upper, and the other at the lower extremity of the staff.

Fig. 2.

The instrument is used in the following manner:—

Supposing that the distance between any two points is required, the first thing to be done is to place the staff, which must be held in a truly vertical position, at one of the points; the omnimeter is set up at the other point, and levelled; the telescope is then directed to the upper white line, *m*, of the staff and clamped; and the inclination of the telescope is then read off on the scale by means of the microscope. On account of the figures being magnified by the microscope, only one number at a time, of the 100 on the scale, can be seen; suppose the reading to be 67 (millimètres), plus the, as yet unascertained, fraction comprised

between this number, and the horizontal thread of the microscope. The value of this fraction is ascertained exactly by means of the micrometer; say that it reads 2,035 on the circle of the micrometer.

This is noted down in the field book to the right of the number 67, already obtained, thus . .	672,035
The operation is repeated in every particular for the lower line, m', of the staff, and we obtain, say	609,400
Difference	62,635

The operation with the instrument is now complete, as we possess the data required for calculating the distance. In fact, this is found by dividing the constant 6,000,000, by the difference 62,635; giving as a result 95·79 m. for the horizontal distance between the points in question.

For let us suppose the staff in position at $m\,m'$, Fig. 3, O to be the point round which the telescope revolves, and A B to represent the observed difference 62,635. From the point O

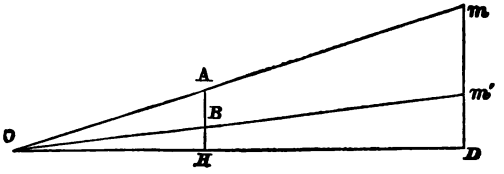

Fig. 3.

let a horizontal line O D be drawn, and let A B be produced to H, and $m\,m'$ to D. Then A B H and $m\,m'$ D are perpendicular to O D; and in the similar triangles O A H and O m D:—

$$\frac{\text{O H}}{\text{A B}} = \frac{\text{O D}}{m\,m'}; \text{ and, therefore O D} = \frac{\text{O H} \times m\,m}{\text{A B}}$$

But O H = 0·20 m. by the construction of the instrument;
$m\,m'$ = 3·00 m., the invariable length of the staff;
A B = 62,635, the quantity obtained, in our example, by the scale.

The last quantity, estimated in mètres, is 0·0062635 m.; and if we substitute for the letters their respective values, we have

$$\text{O D} = \frac{0{\cdot}20 \times 3}{0{\cdot}0062635} = \frac{0{\cdot}6}{0{\cdot}0062685} = \frac{6{,}000{,}000}{62{,}635} = 95{\cdot}79 \text{ mètres.}$$

In the preceding example, the staff was supposed to be placed at one end of the line, and the omnimeter at the other. This mode of operating is not, however, the only one. There are two others; one, by placing the omnimeter in line with the two points, the other, by fixing it at some point out of this line. In either of these modes a staff must be set up at each of the points. In the first case, the total distance is obtained directly, by adding together the back and foresights. In the second case, the distance is obtained by taking the measure of the horizontal angle from the limb, and calculating the base of the triangle, trigonometrically, by means of the angle, thus obtained, and the two sides.

For the establishment of a base of triangulation, the latter method is that which is recommended for adoption; for if we proceed thus by small distances, from ten to twenty mètres on each side or thereabouts, a base line of 1000 mètres may be easily measured within an approximation of 0·004 m.; a result which is quite satisfactory. In fact, if for a distance of ten mètres, the scale gives us the difference 0·06 m., it will give for a distance of 9·99996 m. the difference 0·0600002 m., a quantity appreciable on the circle of the micrometer. The nature of this operation requiring extreme exactness, the staff should have both faces similar to that already described, should be provided with contrivances to ensure its verticality, and its base should be armed with a steel point, to rest on iron pickets driven into the ground.

For the measurement of the slope, or inclined distance, o m', the operation requires further the reading off of the height B H, on the scale. We have then a new proportion:

$$\frac{\text{A B}}{\text{B H}} = \frac{m\,m'}{m'\,\text{D}}\text{; whence } m'\,\text{D} = \frac{m\,m' \times \text{B H}}{\text{A B}};$$

and, then,

$$\text{o}\,m' = \sqrt{m'.\,\text{D}^2 + \text{o D}^2}.$$

In using the omnimeter it has been found that, where extreme accuracy of distance is required, it is not prudent to make the points more than 200 mètres apart. At this distance an approximation within 0·4 m. is obtained. At 500 mètres, by making use of a staff four mètres high, the approximation will be within 0·17 m.; a sufficiently satisfactory result; as, by one fore and one back sight, we can *determine a kilomètre* within 0·34 m.

In levelling, the operation is identical with that just described for the measurement of inclined distances. The difference of altitude is given by the formula

$$m' \text{D} = \frac{m\,m' \times \text{BH}}{\text{AB}};$$

that is, three (mètres), multiplied by the reading at the lower sight divided by the difference of the reading at the two sights.

For distances not exceeding 100 mètres the differences of altitude are obtained within a fraction of a millimètre, and for greater distances, at which the instruments at present in use are inoperative, the measurement can be obtained within a millimètre. This degree of precision is attained because:

1. In placing the instrument it is not necessary to centralise the optical axis.

2. Because the operator has always to point his telescope on the same lines of the staff, which is generally of an invariable length, viz., three mètres.

3. There cannot be a doubt in the readings; as in those of the graduated levelling staves, for which recourse must be had to estimation.

In difficult and hilly ground, levelling with any of the ordinary levels becomes a long and expensive operation, because the sights are necessarily short, and the number of them multiplied, in proportion to the steepness of the incline. The omnimeter allows of levelling points placed at great distances apart, and which make considerable angles with the horizon.

CHAPTER V.

INSTRUMENTS FOR THE DETERMINATION OF CONSIDERABLE HEIGHTS.

In an earlier part of this book the instruments necessary to be used, to obtain an accurate knowledge of the undulations of any portion of ground, have been described, and the method of using them explained. The levels there described, however, were only capable of measuring differences of altitude of a few feet, from each station, or place of observation, and

a continued series of stations had to be selected, and a very large number of observations to be taken, to determine the difference of altitude along a line of considerable length. If the object in view were only to obtain the difference of altitude of two points, where this difference was large, the process of levelling would be altogether inexpedient. The result may then be arrived at by taking angles of elevation of the object, of which the altitude is desired, from different points on a base line; and if this operation be well conducted. it will give the most accurate results; but this mode will occupy considerable time, and involve much labour in computation. For observing, therefore, the height of hills or mountains, barometers and thermometers are much used and, when adapted to such use, are called *hypsometrical instruments.*

The determination of altitudes by the barometer is deduced from the difference in the weights of the superincumbent columns of atmosphere, having the same sectional area, at the two stations at which the observations are made.

The barometer is, in fact, an instrument for measuring the weight of the atmosphere. It was invented in 1643, by Torricelli. Up to his time various phenomena, now known to be caused by the pressure produced by the atmosphere in consequence of its weight, were considered to be accounted for by the statement that Nature abhorred a vacuum. Torricelli, in investigating the phenomenon of water ascending in a pump, found that it could not be raised beyond a certain distance, and consequently, Nature's abhorrence of a vacuum had a limit. What, then, could be the cause of this limitation? To determine this, he tried what would take place with a fluid much heavier than water,—mercury, in fact. He took a glass tube about 4 feet long, sealed at one end and open at the other, and, having filled it with mercury, closed the open end with his finger; he then inverted the tube, and immersing the open end in a basin containing mercury, withdrew his finger, and raised the tube into a vertical position. He found the mercury descend in the tube, and flow out into the basin, until its surface stood 27½ inches above the surface of the mercury in the basin: it then remained stationary. Comparing the height of this column of mercury with the much greater height of water raised in the most perfect pump, he arrived at the conclusion that these heights

were in the inverse ratio of their specific gravities, and, therefore, the difference in the altitudes of the columns depended upon the difference in their weights. He also observed that, in both cases, the phenomenon was produced by cutting off the communication between the atmosphere and the upper extremities of the columns of water, and mercury, while the surface of the fluid, into which their lower ends was immersed, was in direct communication with the atmosphere. He therefore considered that the weight of the atmosphere maintained the elevation of the columns in the tubes, and that the weight of these columns in feet measured the weight of the atmosphere on the same sectional area.

Pascal, a few years later, repeated and extended Torricelli's experiments, making use, not only of mercury, but also of a variety of other liquids, and found that, in all cases, the lighter the liquid, the higher it ascended in the tube. Thoroughly convinced himself of the correctness of Torricelli's theory, he considered what would be the most convincing evidence of its truth to others; and concluded that carrying the tube to a greater height, the column of atmosphere above it would be diminished, and consequently the column in the tube would descend; while, by carrying it to a greater depth the superincumbent column of atmosphere would be increased, and the column would rise in the tube. Experiments made by him upon the mountain Pay de Dôme, near Clermont, in Auvergne, completely proved the correctness of his views. Two tubes, filled with mercury, were carried to the foot of the mountain, their open ends being immersed in mercury, as in Torricelli's experiments; they both stood at 28 inches. One was left at the foot of the mountain, and the other carried up to its top; the mercury in this one kept sinking more and more, the higher it was taken, until at the top it had fallen to 24·7 inches; while upon being brought down again the phenomena were reversed, the mercury rising higher and higher, until, when at the bottom, it was again compared with the tube which had been left there, the heights of the two columns exactly coincided, as at first. Hence it appeared that, in ascending the mountain, the column of atmosphere above the surface of the basin being diminished by that portion of it between the levels of the top and bottom of the mountain, the pressure arising from the weight of this portion was removed from the surface of mercury in the basin, and

the mercury descended in the tube, until its weight was just again counterpoised by the weight of the column of atmosphere above the level of the top of the mountain; and conversely in descending, the column of atmosphere above the basin being increased by a length equal to the height of the mountain, the pressure arising from the weight of this additional length of column, acting on the surface of the mercury in the basin, forced it to ascend the tube, until the weight of the mercury in the tube was again balanced by the weight of the atmospheric column.

Pascal conceived that the lower parts of the atmosphere would be more compressed than the upper, owing to the greater weight of the mass of air above them, and that, from this cause, the rise and fall of the mercury in the tube would not be equal, for equal differences of altitude. This view proved to be correct; the atmosphere, in fact, being compressible and elastic, and its density, at a constant temperature, being in exact proportion to the weight with which it is compressed. This relation between the pressure and density of the atmosphere, was proved by Mariott, and is therefore called Mariott's law. It follows, then, that the stratum of air nearest the earth's surface is the densest, from having to support the weight of all the air above it; and in ascending the strata becomes rarer, from being pressed by lesser quantities of air above them. In fact, for heights in arithmetical progression, the density of the atmosphere would decrease in geometrical progression, if the temperature at the different heights were all the same; but as this is not the case, the relation between the densities at different heights, is considerably modified by the differences of temperature at those heights. Air, under a constant pressure, expands about $\frac{1}{480}$ of its bulk at 32° Fahrenheit for every degree of temperature above that point. The warmer the air too, the greater the amount of aqueous vapour contained in it, and this vapour exerts an ever-varying influence on the mercurial column. The correction due to this cause, however, is very trifling. Sir George Shuckburg made numerous experiments upon the effects of temperature upon the weight of a given column of atmosphere. He found that when the mercurial column, measuring the total atmospheric pressure, was 30 inches, and the temperature 32° Fahrenheit, a rise of 86·85 feet produced a fall in the mercurial column of $\frac{1}{10}$th

of an inch, and that for every additional degree of temperature, the column of atmosphere equivalent to $\frac{1}{10}$th of an inch of mercury, was increased by 0·211 of an inch. From these data the heights of mountains can be obtained, from observation of the barometer and thermometer, in the manner that will be pointed out, after describing the construction of these instruments.

THE MERCURIAL THERMOMETER.

The common mercurial thermometer consists of a glass tube of uniform bore, terminating in a hollow bulb. By holding the bulb over the flame of a spirit-lamp, a considerable portion of air is expelled from the bulb and tube, and the end of the tube, which is open, being immersed in a cup of mercury, as the air within the tube and bulb cools and condenses, the external atmospheric pressure drives a portion of mercury into the tube and bulb. A paper funnel filled with mercury is next to be tied round the open end of the tube, and, the mercury in the bulb being boiled over the spirit-lamp, the whole of the air remaining in the tube will soon be expelled, and its place supplied by mercurial vapour. The instrument being again allowed to cool, the mercurial vapour will be all condensed, and its place supplied by mercury, driven down the funnel, till both bulb and tube are completely filled with mercury. Lastly, when the mercury has cooled down nearly to the highest temperature intended to be measured by the instrument, the end of the tube, hitherto open, is to be perfectly sealed by means of the blowpipe, and as the mercury afterwards continues to cool, it will be considerably condensed, and, sinking down, will leave a vacuum in the upper part of the tube.

The thermometer has now to be graduated, and, for this purpose, it must first be immersed in melted snow, and, when the mercury has sunk as low as it will, a graduation must be marked opposite the extremity of the mercurial column for the freezing point. The thermometer must next be immersed in the vapour of water, boiling under a given atmospheric pressure, and, when the mercury is again stationary, another graduation must be marked, opposite the extremity of the mercurial column, for the boiling point. The distance between these two graduations is then to be divided into a determinate number of equal parts, and, continuing to

mark off divisions of the same extent, in both directions, to the extremities of the tube, the instrument will be completly graduated.

In the centigrade thermometer, the freezing point is 0°, and the boiling point 100°; in Reaumur's, the freezing point is marked 0°, and the boiling point 80°; and in Fahrenheit's, which is the thermometer in common use in this country, the freezing point is marked 32°, and the boiling point 212°. Assuming, then, the boiling point to have been determined under the same pressure for all three, and consequently to indicate the same absolute temperature, we have—

$$\tfrac{1}{5}\,\text{C}^\circ = \tfrac{1}{4}\,\text{R}^\circ = \tfrac{1}{9}\,(\text{F}^\circ - 32^\circ);$$

if C,° R,° and F,° represent respectively the degrees of the centigrade thermometer of Reaumur's, and of Fahrenheit's, denoting the same absolute temperature.

The mercurial thermometer was constructed under the idea, that equal differences of temperature would cause the bulk of a body to vary by equal differences. Now, except in the case of gases, this assumption is not borne out by the facts of the case; but by a fortunate coincidence, the increasing rate of the expansion of the mercury is exactly compensated by the comparatively small expansion of the glass, so that the indications of the temperature given by the ordinary mercurial thermometer are strictly accurate.

The mere fact of speaking of the indications of a thermometer as accurate implies, that there is some mode of testing this accuracy, and, consequently, some idea of comparing temperatures independently of the observation of the variation in the bulk of a body, produced by a difference of temperature; and, in fact, the comparison of temperatures depends on the following considerations:—

1°. Two bodies are said to have the same temperature, if when placed in contact the temperature of either remains unaltered by the other.

2°. When bodies of different temperature are placed in contact, the temperature of the hotter body decreases, and that of the colder increases, till both become of the same temperature.

3°. If the bodies thus placed in contact be both of the same material, and be equal to each other in weight, the in-

crease of temperature in one will be equal to its decrease in the other, and the product of the whole mass into the temperature will remain the same.

In order to test the accuracy of the common thermometer, Dr. Brooke Taylor heated two equal weights of water, till their temperatures, as indicated by the thermometer, were respectively 100° and 200°; and on mingling these bodies of water together, the thermometer indicated correctly 150°, as the temperature of the mixture.

THE BAROMETER.

There are various forms of the barometer, to suit the various circumstances under which it is to be used; but in all of them there is a straight tube, about 33 inches long, closed at one end, for holding the column of mercury, of which the altitude is to be observed. This is called the barometer tube, and, being filled with mercury, the open end of it is placed in communication either with an open cistern containing mercury, or with a bent tube containing mercury, which is exposed to the action of the atmosphere.

Fig. 1. represents a form of barometer, called the standard barometer, adapted for use in fixed observatories. The bore of the barometer tube, A C, should not be less than one-fourth of an inch diameter, and if it be one-third of an inch it is better, in order to avoid any considerable error from the capillary depression. The diameter of the open end, A B, of the barometer should be as large as it can conveniently be made, in order that the variation in the altitude of the mercury in A C should affect as little as possible the altitude of the surface A B. In order, however, to obtain the true altitude of the mercury within this barometer, the position of the surface A B must be taken into account, as well as that of the extremity of the mercurial column A C, the height of which above an assumed zero point is given by the scale attached to the barometer. This is done by making the scale movable, and terminating in an ivory point: when this point and its reflection appear to touch one another, the height indicated is correct.

Fig. 1.

Tubes of small diameters require correction for capillarity. The mercury is depressed in the glass tube from the repul-

sion between the two substances, and the following corrections must be added :—

Diameter of tube.	Correction.
inch.	
0·25	0·020
0·30	0·015
0·40	0·007
0·45	0·005
0·60	0·002

The syphon barometer, Fig. 2, gives the altitude of the mercurial column independently of errors from capillary depression; for, on account of the equal size of the bore throughout the tube, the extremities of the columns A and C are equally depressed.

Fig. 2.

In the ordinary form of the portable barometer the tube is immersed in a reservoir with a leathern bottom, and furnished with a screw *f*, by turning which the mercury can be forced up, and made entirely to fill the tube, to prevent it from jerking about, and injuring the instrument during its carriage from place to place. This screw can be made to regulate the surface of the mercury in the cistern, and always bring it into line with the zero of the scale. For this purpose the instrument is furnished with a gauge or float *h*. The gauge consists of a small ivory cylinder, fixed to a float of cork, which rests on the top of the mercury. The upper end of this cylinder works in a groove, hollowed out of a second piece of ivory, which is fixed to the instrument, and has a fine line upon it denoting the zero of the scale: the floating cylinder has a corresponding fine line cut upon it; and, before observing the reading of the instrument, the two lines must be brought into exact coincidence by turning the screw *f*.

Let *a b*, Fig. 3, be the glass tube plunged into the

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mercury in the cistern C, and D be the surface-line of the fluid in the cistern, made level with the commencement of the scale, in the construction of the instrument: then the extremity of the mercurial column in the tube at this time is called the *neutral point*. When the mercury rises in the tube, a portion equal to the rise leaves the cistern, and the surface-line falls towards the dotted line *e*; and, being lower than the surface from which its neutral point was measured, the indicated variation in the atmosphere is too little; but turn the screw *f* forwards, until the lines on the float *h* coincide, and the mercury then records the exact change; when a depression occurs, the mercury, sinking from the tube into the cistern, raises the surface-line towards *g*: in this case the screw *f* must be turned back, until the leather at the bottom of the cistern be sufficiently loosened to allow the mercury to assume its proper level at the surface D.

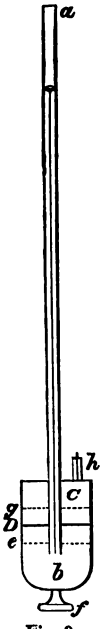


Fig. 3.

When there is not a gauge to the barometer, the relative capacities of the cistern and tube are ascertained by experiment, in the construction of the instrument, and marked thereon, as is also its neutral point.

The correction to be applied to the reading of the scale, to obtain the correct height, may be computed as follows:—

Let h be the neutral point altitude of the extremity of the mercurial column, when the zero point of the scale coincides with the surface D, and let h' be its apparent altitude in any other case; let also K represent the sectional area of D, and k that of the tube; so that $\frac{K}{k}$ is the capacity of the cistern relatively to the tube, which is marked on the instrument; then the distances, through which the surfaces in the tube, and cistern, will rise and fall respectively, will be manifestly inversely proportional to the areas of their surfaces; if, therefore, $\delta h'$ represent the required correction, viz., the distance through which the mercury falls in the cistern,

$$h' - h : \delta h' :: K : k.$$

$$\therefore \delta h' = \frac{k}{K}(h' - h),$$

and the true altitude of the barometer is given by the equation

$$h' + \delta h' = h' + \frac{k}{K}(h' - h).$$

When the indicated height, h', is above the neutral point h, $h' - h$ is positive, and the correction $\delta h'$ is to be added, to give the correct height; but when the mercury is below the neutral point, $h' - h$ is negative, and the correction $\delta h'$ is to be subtracted, to give the correct height. Hence the following rule:—

When the mercury in the tube is *above* the neutral point, the difference between it and the neutral point is to be divided by the capacity, and the quotient *added* to the observed height, to give the correct height; and, when the mercury is *below* the neutral point, the difference is to be divided as before, and the quotient *subtracted* from the observed height will give the correct height.

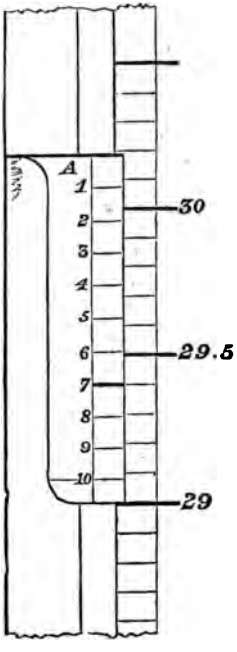
Ex.—Let $\frac{K}{k}$, or the capacity of the cistern relatively to the tube, be 40, and the neutral point altitude be 30 inches.

Ex. 1.—	Observed height		30·480
	Neutral point . .	30·000	
	Height above neutral point	+·480	
	Correction		+.012
	Correct height		30·492
Ex. 2.—	Observed height		28·720
	Neutral point . .	30·000	
	Height above neutral point	—1·280	
	Correction		—·032
	Correct height		28·688

The portable, or mountain barometer, has received great improvements. It is now produced in a form, in which the

mercury is confined wholly by glass and iron, and can be made absolutely free from shake in the tube, so as to ensure safety in rough transit. The total height of the mercurial column is read directly against the light at both ends, and with no *structural* corrections for expansion of instrument, except as between brass and glass, the co-efficients of both being well-known.

The greatest range of the barometer in any one spot does not exceed 3½ inches, and consequently, in barometers intended for meteorological observations, it is unnecessary to graduate more than a few inches of the tube: the divisions, therefore, commence at 27 inches, and are continued to 31 inches. The graduations on the mountain barometer, for measuring great heights, commence at 15 inches, and are carried on to 33 inches.



In the common, or meteorological barometer, each inch is divided into ten equal parts, and on the vernier, eleven tenths of an inch are divided into ten equal parts, so that each part is equal to eleven hundredths of an inch, or one tenth and one hundredth. By means of this vernier, then, the height of the column is indicated to the hundredth part of an inch.

The annexed figure shows the arrangement and mode of reading the barometer.

Here the pointer or index, A, of the vernier is above the division, indicating 30·1 inches on the barometer scale, and the division, marked 7 on the vernier, coincides with a division on the barometer scale: the reading is therefore 30·17.

In the mountain and standard barometers, 51 tenths of an inch on the vernier are divided into 50 equal parts, so that each part is equal to 51 five-hundredths of an inch, or one tenth, and one five-hundredth. By means of this vernier,

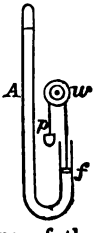
then, the height of the column is read off to the five-hundredth part of an inch.

A thermometer is attached to the barometer, to indicate the temperature of the mercury in the cistern. The expansion of mercury is $\frac{1}{5550}$ of its bulk, for each degree of Fahrenheit between 32° and 212°; and, in making observations for the determination of altitudes, it is indispensable that the attached thermometer should be read off for the temperature of the mercury, and a detached thermometer for the determination of the temperature of the atmosphere, simultaneously with the observation of the height of mercury in the barometer.

Before taking an observation the instrument should be gently tapped, to prevent any adhesion of the mercury to the tube, and if the instrument be provided with a gauge, this should be adjusted, to bring the surface of the mercury in the cistern in a line with the zero of the scale; the vernier should then be brought level with the top of the mercury, and if light is admitted from behind, this arrangement can be perfected by making the lower part of the pointer tangential to the convex part of the mercury in the tube. In reading off, care must be taken to place the eye on a level with the top of the mercurial column, as by placing it above, the reading would be too low, and by placing it below, the reading would be too high, or, in other words, there would be an error from parallax.

THE WHEEL BAROMETER.

In the wheel barometer, a weight, *f*, floats on the surface of the mercury, in the open end of the bent tube A, and a string attached to the float *f* passes over a small wheel *w*, and is then attached to a second weight *p*. As the mercury rises and falls, the float *f* moves with it, and the string turns the wheel, the axis of which passes through a dial-plate and carries an index, like the hand of a clock, which points to the altitudes figured on the dial-plate. The wheel barometer is by its construction endowed with so many sources of error, that it cannot be depended upon for correct indications of the height of the barometric column; although it readily shows if the mercury be in a rising or falling state, as a small



variation in the barometric column produces a considerable movement of the index. It may rather be considered as an ornamental piece of furniture, than as having the slightest pretensions to be called a scientific instrument.

THE ANEROID BAROMETER.

The action of the *aneroid* barometer, invented by M. Vidi, of Paris, for ascertaining the variations of the atmosphere, depends on the effect produced by the pressure of the atmosphere on a metallic box hermetically sealed, from which the air has been previously exhausted. It has already been explained, that the weight of the column of the mercurial barometer is counterpoised by the weight of the atmosphere, and that the variations in the weight of the atmosphere are shown by the variations in the *length* of this

Fig. 1.

column, and measured in inches and tenths; but in the aneroid, an index traversing a dial records the changes in the weight or *pressure* of the atmosphere on a *given surface, suppose a* square inch; and it would therefore, have greatly

facilitated the comprehension of the action of the instrument, had the dial been graduated to show the difference of the atmospheric pressure in absolute weight or pounds.

Simultaneous observations of the Aneroid and Mercurial Barometer for the month of March, 1848.

Date.	9 A.M.		Thermometer.	3 P.M.		Thermometer.
	Aneroid barometer.	Standard barometer.		Aneroid barometer.	Standard barometer.	
	in.	in.	degrees.	in.	in.	degrees.
1	28·66	28·67	50	28·80	28·80	50
2	29·15	29·15	50	29·29	29·29	50
3	29·88	29·90	48			
4	30·12	30·14	46	30·11	30·12	51
5	29·82	29·83	46	29·77	29·77	46
6	29·87	29·88	46	29·84	29·85	47
7	29·81	29·82	45			
8	30·28	30·29	44	30·22	30·25	46
9	29·98	29·99	49	29·89	29·90	52
10	29·44	29·45	51	29·41	29·42	51
11	28·91	28·93	50	28·84	28·85	50
12	28·69	28·70	48	28·79	28·80	48
14	29·76	29·78	47	29·85	29·88	49
15	29·76	29·78	46	29·64	29·65	49
16	29·49	29·50	48	29·49	29·49	49
17	29·34	29·35	49	29·34	29·34	46
18	29·44	29·45	46	29·37	29·37	52
19	29·18	29·20	48	29·12	29·12	51
20	28·98	28·99	48	28·97	28·98	49
21	28·80	28·81	49	29·13	29·13	49
22	29·60	29·60	47	29·67	29·68	51
23	29·67	29·70	54	29·80	29·80	54
24	30·02	30·02	55	30·10	30·10	55
25	30·16	30·16	52	30·11	30·11	54
26	29·89	29·90	53	29·80	29·80	54
27	29·70	29·70	53	29·70	29·70	56
29	29·91	29·91	54	29·91	29·90	56
30	29·81	29·80	55	29·81	29·80	58
31	29·98	29·98	58	30·00	30·00	65

Though for purely scientific purposes the aneroid is at present far removed from competition with the mercurial barometer, it nevertheless has some advantages in its extreme sensibility and its portability. Much has been urged against its variations from temperature; but in a range from 28° to 80°, these seldom exceed a tenth of an inch; and it must

be borne in mind, that if the mercurial barometer be subjected to the same range, it will be equally affected; only in the latter case, the cause of the variation is satisfactorily established, and its exact amount for every degree of temperature accurately determined.

The observations recorded in the foregoing table show that, in the popular use of the aneroid, the same corrections for temperature may be taken as for the mercurial barometer.

Fig. 1 represents the external appearance of the instru-

Fig. 2.

ment. It is four inches and three-quarters in diameter across the face, and one inch and three-quarters in thickness. The pressure of the atmosphere is indicated by a hand pointing to a scale, which is graduated to correspond with the common barometer: thermometers are placed on the face, one of which is essential.

Fig 2 represents the internal construction, as seen when the face is removed, but with the hand still attached. *a* is a flat circular box, made of some white metal, exhausted of air through the short tube *b*, which is subsequently made air-tight by soldering: the upper and lower surfaces of the box *are corrugated* in concentric circles, which gives it greater

elasticity; and the box is fixed to the bottom of a metallic case, which encloses the mechanism of the whole instrument. In the centre of the *upper* surface of the elastic box is a solid cylindrical socket *x*, about half an inch high, to the top o: which the *principal lever*, *c d e*, is attached; and this lever which brings the box into a state of tension by separating the surfaces, rests partly upon a spiral spring *d*, and partly on two fulcra having knife edges, with perfect freedom of motion. The end, *e*, of the large or principal lever is attached to a second lever *f*, from which a fine watch-chain *g* extends to *h*, where it works on a drum, attached to the arbour of the hand. A hair-spring at *h*, the attachments of which aro made to the metallic plate *i*, regulates the motion of the hand.

As the weight of the atmosphere is increased or diminished, so is the surface of the corrugated elastic box depressed or elevated, as is also at the same time the spiral spring *d*, upon which the principal lever rests; and this motion is communicated through the levers to the arbour of the hand at 1 The tension of the box in its construction is equal to 44 lbs. At the back of the aneroid is a screw to adjust the hand to the height of any standard mercurial barometer: for comparative observations the aneroid must be placed in the position for which the adjustment is made.

A perspective view of the interior of the Aneroid.

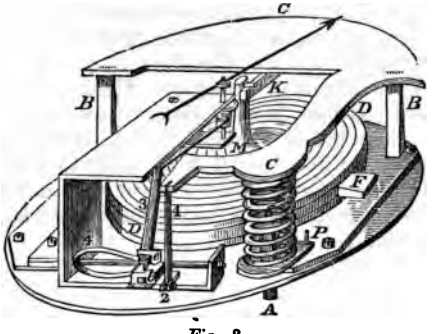
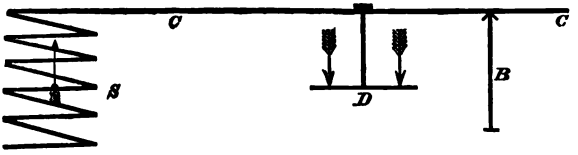


Fig. 3.

A. Screw adjusting the hand.
B B. *Fulcrums.*

C C. Principal lever.
D D. Vacuum vase.
1. Vertical rod connecting lever C C with levers 2 and 3.
e b. Adjusting screws for leverage.
S. Spiral spring.
M. Socket in vacuum vase.
K. Pin attached to socket.



D. Vacuum vase (the arrows indicate the downward pressure of the atmosphere).
C. Principal lever.
B. Fulcrum.
S. Spring.

APPLICATION OF THE BAROMETER TO THE DETERMINATION OF DIFFERENCES OF ALTITUDE.

It has already been stated (p. 95) the density of the atmosphere would decrease in geometrical progression, for altitudes in arithmetical progression, and, since this density also varies directly as the pressure to which it is subjected, and which is measured by the height of the barometric column, it follows that, if at different altitudes these columns decrease in geometric progression, the altitudes will increase in arithmetical progression, and will, therefore, be proportional to the logarithms of the barometric columns. Hence, if the temperature remained constant, the difference of two altitudes would vary as the difference of the logs. of the barometric columns at those altitudes; so that, if h be taken to represent the height of a higher station above a lower one, and if B be the height of the barometer at the *lower* station, and b the height at the *higher* station, we should have

$$h = k \log. \frac{B}{b};$$

where k is a constant quantity, to be determined by experiment.

The following Table exhibits the results of Sir George

Shuckburgh's experimental determination of the number of feet in a column of the atmosphere, equivalent in weight to a like column of mercury, $\frac{1}{10}$ of an inch high for every five degrees of temperature, ranging from 32° to 80°, when the barometer stands at 30 inches.

Thermometer.	Feet.
32°	86·85
35	87·49
40	88·54
45	89·60
50	90·66
55	91·72
60	92·77
65	93·82
70	94·88
75	95·93
80	96·99

From an examination of this table, we see that the value of h varies with the temperature by $\frac{1}{440}$ of its value at 55°, for each degree of Fahrenheit above or below 55°: hence, if K be the value of k for temperature of 55°, for any other temperature, t, we shall have $k = \text{K}\left(1 + \frac{t-55^\circ}{440}\right)$

$$\text{and } h = \text{K} \log. \frac{\text{B}}{b}\left(1 + \frac{t-55^\circ}{440}\right)$$

Now the value of $\log \frac{\text{B}}{b}$ is given by the equation

$$\log. \frac{\text{B}}{b} = 2\left(\frac{\text{B}-b}{\text{B}+b}\right) + \left(\frac{\text{B}-b}{\text{B}+b}\right)^3 + \&c.$$

and, when $\frac{\text{B}-b}{\text{B}+b}$ is a small fraction, all the terms in this series, except the first, may be neglected as inconsiderable, and we

have log. $\frac{B}{b} = 2\,\frac{B-b}{B+b}$. In this case, then,

$$h = 2\,K\,\frac{B-b}{B+b}\left(1 + \frac{t-55^\circ}{440}\right)$$

t representing the temperature in degrees Fahrenheit.

Also, when $B - b = \frac{1}{10}$ of an inch,
$B = 30$ inches,
and $t = 55$,

the same table gives 91·72 feet for the value of h.

To determine the value of $2\,K$ we have, therefore, the equation

$$91{\cdot}72 = 2\,K\,\frac{\frac{1}{10}}{59{\cdot}9},$$

$$= \frac{2\,K}{600} \text{ nearly;}$$

$$\therefore\ 2\,K = 600 \times 91{\cdot}72,$$

$$= 55032 \text{ nearly},$$

and, this value being in excess, we may take for the value of $2\,K$, the more simple number 55,000; we have then the value of h given by the equation,

$$h = 55{,}000\,\frac{B-b}{B+b}\left(1 + \frac{t^\circ - 55^\circ}{440}\right).$$

If the fall exceed 5 inches, $\frac{B-b}{B+b}$ should be replaced by log. $\frac{B}{b}$; but for any amount of fall less than this, the above formula will give results sufficiently accurate.

It has already been stated, that the barometer has a thermometer attached for the purpose of indicating the temperature of the instrument itself. In the determination of height when the difference of two stations at which observations are made is considerable, there is generally also a considerable difference in the temperatures at the two stations, and it is important to take account of the indication of the attached thermometer. The barometric heights should, therefore, be corrected for the variation of temperature, before applying the formula for the computation of the difference of altitude.

The following tables show the correction to be applied to

the reading of the barometer, for the temperatures indicated by the attached thermometer.

In applying the correction for the attached thermometer it is to be observed, that it is only the difference in the temperature at the two stations which will apparently affect the result, and that consequently, as long as the barometric heights are reduced to the *same* temperature, it matters not what that temperature may be.

The law of variation of the aneroid barometer for difference of temperature is not known, but from the closeness of its indications with those of the standard barometer, the correction may be assumed to be the same with that for the mercurial barometer. In many cases, too, the difference of temperature at the different stations is so small that the corrections for them may be neglected.

TABLE I.

Corrections for Temperature to be applied to Barometers mounted on Brass Scales.

Temp. of Fahr.	Inches. 24·5	Inches. 25·0	Inches. 25·5	Inches. 26·0	Inches. 26·5	Inches. 27·0	Inches. 27·5	Inches. 28·0	Inches. 28·5	Inches. 29·0	Inches. 29·5	Inches. 30·0	Inches. 30·5	Temp. of Fahr.
°														°
24	+·010	+·010	+·010	+·011	+·011	+·011	+·011	+·011	+·012	+·012	+·012	+·012	+·012	24
26	·006	·006	·006	·006	·006	·006	·006	·006	·006	·007	·007	·007	·007	26
28	+·001	+·001	+·001	+·001	+·001	+·001	+·001	+·001	+·001	+·001	+·001	+·001	+·001	28
30	−·003	−·003	−·004	−·004	−·004	−·004	−·004	−·004	−·004	−·004	−·004	−·004	−·004	30
32	·008	·008	·008	·008	·008	·009	·009	·009	·009	·009	·009	·009	·010	32
34	·012	·012	·013	·013	·013	·013	·014	·014	·014	·014	·015	·015	·015	34
36	·017	·017	·017	·017	·018	·018	·019	·019	·019	·020	·020	·020	·020	36
38	·021	·021	·022	·022	·023	·023	·023	·024	·024	·025	·025	·026	·026	38
40	·025	·026	·026	·027	·027	·028	·028	·029	·029	·030	·030	·031	·031	40
42	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	·036	·036	·037	42
44	·034	·035	·035	·036	·037	·037	·038	·039	·040	·040	·041	·042	·042	44
46	·038	·039	·040	·041	·042	·042	·043	·044	·045	·045	·046	·047	·048	46
48	·043	·044	·045	·045	·046	·047	·048	·049	·050	·051	·052	·052	·053	48
50	·047	·048	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	50
52	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	·064	52
54	·056	·057	·058	·059	·060	·062	·063	·064	·065	·066	·067	·068	·070	54
56	·060	·061	·063	·064	·065	·066	·068	·069	·070	·071	·073	·074	·075	56
58	·064	·066	·067	·068	·070	·071	·073	·074	·075	·077	·078	·079	·081	58
60	·069	·070	·072	·073	·075	·076	·077	·079	·080	·082	·083	·085	·086	60
62	·073	·075	·076	·078	·079	·081	·082	·084	·085	·087	·088	·090	·091	62
64	·078	·079	·081	·083	·084	·086	·087	·089	·090	·092	·094	·095	·097	64
66	·082	·084	·085	·087	·089	·090	·092	·094	·096	·097	·099	·101	·102	66
68	·086	·088	·090	·091	·094	·095	·097	·099	·101	·102	·104	·106	·108	68
70	·091	·093	·095	·096	·098	·100	·102	·104	·106	·108	·109	·111	·113	70
72	·095	·097	·099	·101	·103	·105	·107	·109	·111	·113	·115	·117	·119	72
74	·099	·102	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	·124	74
76	·103	·106	·108	·110	·112	·114	·117	·119	·121	·123	·125	·127	·129	76
78	·108	·111	·113	·115	·117	·119	·122	·124	·126	·128	·130	·133	·135	78
80	−·114	−·115	−·117	−·119	−·122	−·124	−·126	−·129	−·131	−·133	−·136	−·138	−·140	80

Enter with approximate height of the barometer at the top of the table, and the degree of the thermometer on the side of the page; then take out the correction with its proper sign.

Let barometer read 29·000 Thermometer attached — 50°
Correction ..... — ·056

TABLE II.

*Corrections for Temperature to be applied to Barometers mounted in wood.**

Temperature.	Inches. 28·5	Inches. 29·0	Inches. 29·5	Inches. 30·0	Inches. 30·5	Temperature.	Inches. 28·5	Inches. 29·0	Inches. 29·5	Inches. 30·0	Inches. 30·5
°						°					
25	+ ·017	+ ·017	+ ·018	+ ·018	+ ·018	53	— ·053	— ·053	— ·054	— ·054	— ·055
26	·015	·015	·015	·015	·015	54	·055	·055	·056	·057	·058
27	·012	·012	·012	·012	·012	55	·056	·057	·058	·059	·060
28	·009	·010	·010	·010	·010	56	·059	·059	·060	·062	·063
29	·007	·007	·007	·007	·007	57	·062	·062	·062	·064	·065
30	·005	·005	·005	·005	·005	58	·064	·064	·065	·066	·067
31	+ ·002	+ ·003	+ ·003	+ ·003	+ ·003	59	·066	·067	·068	·069	·071
32	·000	·000	·000	·000	·000	60	·068	·069	·071	·072	·073
33	— ·002	— ·002	— ·002	— ·002	— ·003	61	·072	·072	·073	·074	·075
34	·005	·005	·005	·005	·005	62	·074	·074	·076	·077	·078
35	·007	·007	·008	·008	·008	63	·077	·077	·078	·080	·081
36	·010	·010	·011	·011	·011	64	·080	·080	·081	·083	·084
37	·013	·013	·013	·014	·014	65	·081	·082	·083	·085	·086
38	·015	·015	·015	·015	·015	66	·084	·085	·086	·087	·088
39	·018	·018	·018	·019	·019	67	·088	·088	·089	·090	·091
40	·020	·020	·020	·021	·021	68	·090	·090	·091	·093	·094
41	·023	·023	·023	·024	·024	69	·092	·092	·093	·095	·097
42	·025	·025	·025	·026	·026	70	·093	·094	·096	·098	·100
43	·028	·028	·028	·029	·030	71	·096	·097	·098	·100	·102
44	·030	·030	·030	·031	·032	72	·099	·099	·101	·103	·105
45	·032	·032	·033	·033	·034	73	·102	·102	·103	·106	·108
46	·035	·035	·036	·036	·036	74	·104	·105	·106	·108	·111
47	·037	·037	·038	·038	·038	75	·105	·107	·109	·112	·114
48	·039	·039	·040	·040	·040	76	·107	·109	·112	·115	·117
49	·041	·041	·043	·043	·043	77	·110	·112	·114	·117	·120
50	·044	·045	·046	·047	·047	78	·112	·114	·117	·120	·123
51	·047	·047	·049	·049	·050	79	·115	·117	·120	·123	·127
52	— ·050	— ·050	— ·051	— ·051	— ·052	80	— ·117	— ·119	— ·122	— ·126	— ·130

* The corrections in the above Table are due to the expansion of mercury only.

Enter with the approximate height of the barometer at the top of the table, and the degree of the thermometer on the left side of the page; then take out the correction with its proper sign.

Let barometer read.....	29·500	Thermometer attached = 68°
Correction by table.....	·091	
Correct height for 32°	29·409	

The following table gives the value of the factor $\bar{\kappa}$ corrected for temperature:—

TABLE III.

Thermometer.	Factor.	Thermometer.	Factor.	Thermometer.	Factor.
degrees.		degrees.		degrees.	
30	25,928	47	27,006	64	28,083
31	25,992	48	27,069	65	28,146
32	26,055	49	27,132	66	28,210
33	26,118	50	27,196	67	28,273
34	26,182	51	27,259	68	28,336
35	26,245	52	27,322	69	28,400
36	26,308	53	27,386	70	28,463
37	26,372	54	27,449	71	28,527
38	26,435	55	27,513	72	28,590
39	26,499	56	27,576	73	28,653
40	26,562	57	27,639	74	28,717
41	26,625	58	27,703	75	28,780
42	26,689	59	27,766	76	28,843
43	26,752	60	27,829	77	28,907
44	26,815	61	27,893	78	28,970
45	26,879	62	27,956	79	29,034
46	26,942	63	28,020	80	29,097

APPLICATION OF THE PRECEDING TABLE.

Let m = the mean height of the two barometers, or $\frac{B + b}{2}$

d = the difference of the two heights,

f = the number corresponding to the mean of the readings of the detached thermometer,

x = difference of altitude at the two stations

then, $x = f\frac{d}{m}$.

EXAMPLE.

At the lower station—

Let the barometer stand at 30·08 inches,
attached thermometer 59°,
detached ,, 60°.

At the higher station—

Let the barometer stand at 26·40 inches,
attached thermometer 47°,
detached ,, 46°.

The corrections for the barometer from Table I. are ·08 and ·04, respectively. The corrected heights, therefore, are 30 inches, and 26·36 inches; their mean height is 28·18 inches, and their difference 3·64 inches. The mean of the readings of the detached thermometer is 53°, and opposite this number in Table III. is 27,386; therefore,

$$x = 27{,}386 \frac{3{\cdot}64}{28{\cdot}18} = 3{,}537 \text{ feet.}$$

The following table, made by computing the value of $\frac{m}{f}$, may be much more easily applied, to give results differing but slightly in their correctness:—

Mean of barometric readings.	Mean Temperature.					
	30°	40°	50°	60°	70°	80°
25	·00096	·00994	·00092	·00090	·00088	·00086
26	·00100	·00098	·00096	·00093	·00091	·00089
27	·00104	·00102	·00099	·00097	·00095	·00093
28	·00107	·00105	·00103	·00101	·00098	·00096
29	·00112	·00109	·00107	·00104	·00102	·00100
30	·00115	·00113	·00110	·00108	·00105	·00103

The difference of the barometric readings, divided by the appropriate number from this table, gives at once the difference of height sought.

EXAMPLE.

Barometer at lower station	30·00	Mean temperature	53°
" higher "	26·36	" barometer	28·18
Difference	3·64		

Corresponding tabular number, ·00103.

```
·00103)3·64(3534
       309
       ---
        550
        515
        ---
         350
         309
         ---
          410
```

The result 3534 differs by only 3 feet from that already obtained by the table of factors.

Perhaps, however, the simplest mode of all is to form a table of elevations corresponding to the heights of mercury in the barometer, assuming the zero point to correspond to 30 inches of the barometer, with the thermometer at 55°.

The altitudes corresponding to the readings of the barometer at any two stations being taken from the table, the difference between their altitudes gives the difference of altitude between the two stations, subject only to the correction for the temperature.

The following table is computed from the formula:—

$$h = 55{,}000 \frac{30 - b}{30 + b}$$

the temperature being 55°.

Height of barometer. b.	Altitude of station. h.	Height of barometer. b.	Altitude of station. h.
in.	feet.	in.	feet.
31·0	—902	28·5	1411
30·9	813	28·4	1508
30·8	724	28·3	1605
30·7	634	28·2	1702
30·6	545	28·1	1799
30·5	455	28·0	1897
30·4	364	27·9	1996
30·3	274	27·8	2095
30·2	183	27·7	2194
30·1	91	27·6	2293
30·0	0	27·5	2392
29·9	+92	27·4	2491
29·8	184	27·3	2592
29·7	276	27·2	2692
29·6	368	27·1	2793
29·5	462	27·0	2895
29·4	556	26·9	2997
29·3	650	26·8	3099
29·2	744	26·7	3201
29·1	838	26·6	3304
29·0	932	26·5	3407
28·9	1028	26·4	3511
28·8	1123	26·3	3615
28·7	1219	26·2	3719
28·6	1315	26·1	3824
—	—	26·0	3929

EXAMPLES OF THE USE OF THE PRECEDING TABLE.

	in.		ft.
1. Barometer at higher station	29·5	Corresponding altitude in table . . .	462
" lower "	30·1	" " . . .	—91
		Difference of altitudes	553
Assumed temperature . .	55°		
Mean temperature . . .	44°	Correction for temperature, $\frac{11}{440} \times 553 =$	14
	11		539

Hence the upper station is 539 feet above the lower.

Computed by the factor for 44° in Table III., at p. 114, the difference of the altitudes = 539·9.

	in.		ft.
2. Barometer at higher station	26·66	Corresponding altitude	3242
" lower "	29·89	" "	101
		Difference of altitudes	3141
Assumed temperature . . .	55°		
Mean temperature	50	Correction for temperature $\frac{5}{440} \times 3141 =$	35
	5	Corrected difference of altitudes . . .	3106

Computed by the factor for 50° in Table III., at p. 114. the difference of altitudes is 3106·7.

The following modification of the above table gives the barometric readings for each 100 feet of altitude:—

—1000	31·11	1600	28·31
900	31·00	1700	28·20
800	30·88	1800	28·10
700	30·77	1900	28·00
600	30·66	2000	27·90
500	30·55	2100	27·79
400	30·44	2200	27·69
300	30·33	2300	27·59
200	30·22	2400	27·49
100	30·11	2500	27·39
0	30·00	2600	27·29
+ 100	29·89	2700	27·19
200	29·78	2800	27·09
300	29·67	2900	27·00
400	29·57	3000	26·90
500	29·46	3100	26·80
600	29·35	3200	26·70
700	29·25	3300	26·60
800	29·14	3400	26·51
900	29·03	3500	26·41
1000	28·93	3600	26·31
1100	28·82	3700	26·22
1200	28·72	3800	26·12
1300	28·62	3900	26·03
1400	28·51	4000	25·93
1500	28·41		

In the table thus modified, if the distance between the two readings of the barometer be taken off with compasses, or measured on a slip of paper, it will extend on the column of heights from zero to the difference of altitude, at the assumed temperature of 55°.

If the column of altitudes be arranged on a slide, adapted to a groove, in a rule having the column of barometric readings marked upon it, then by merely setting the zero of the slide to the barometric reading of any station at starting, the altitudes of all points passed over, at the assumed temperature of 55°, will at once be read on the slide, opposite the observed height of the barometer at those points. A slide-rule of this kind is manufactured by Mr. West, of Charing Cross, from the design of its inventor, Mr. Whitley, of Penarth, Truro.

Mr. Whitley makes a length of one inch on the slide correspond to 200 feet of altitude, and, dividing the inch into 20 equal parts, each division indicates 10 feet difference of altitude: the corresponding barometric heights on the fixed scale then differ, on the average, by about ·01′, so that the difference of altitude corresponding to each variation of $\frac{1}{100}$ of an inch of the barometer, is at once read on the slide.

A slide-rule thus constructed, 25 inches long, would extend from 31·11 inches of the barometer, corresponding to a depression of 1,000 feet, to 25·93 inches, corresponding to an altitude of 4,000.

Nothing can be more simple, than to set out with such a rule, and an aneroid barometer, and note the altitudes passed over, even while travelling on a railway.

METEOROLOGICAL PHENOMENA OF THE BAROMETER.

The following account of the meteorological phenomena indicated by the barometer, is extracted from a manual of the barometer by Mr. Belville, of the Royal Observatory, Greenwich, from which we have derived much assistance in this part of our work.

Strong winds in the winter from the west with a steady high pressure, invariably bring a high temperature and very little rain, winds from the east, a low temperature and sharp frosts.

If the mercury fall during a high wind from the south-west, south-south-west, or west-south-west, an increasing storm is

probable; if the fall be rapid, the wind will be violent, but of short duration; if the fall be slow, the wind will be less violent, but of longer continuance; the disturbing cause is probably the same in each case, but its intensity unequal: nearly all our high winds from the south-west come with a falling barometer.

If the depression of the mercury be sudden and considerable with the wind due west, a violent storm may be expected from the north-west or north, during which the mercury will rise to its former height. If the mercury fall with the wind at north-west, or north, a great reduction of temperature will follow, in the winter severe frosts, in the summer cold rains.

A steady and considerable fall of the mercury during an east wind denotes that the wind will soon go round to the south, unless a heavy fall of snow or rain immediately follow; in this case the *upper* clouds usually come up from the south. The deep snow of the severe winter of 1814 was a notable instance.

The lowest depressions occur with the wind at south and south-east, when much rain falls, and frequently short and severe gales blow from these points. In the winter months, sudden depressions of the mercury with the wind in these quarters are attended with electrical phenomena.

A fall of the mercury with a south wind is invariably followed by rain in greater or less quantities.

A falling barometer with the wind at north brings the worst weather: in the summer, rain and storm follow; in the winter and spring, deep snows and severe frosts. This case is of rare occurrence.

A great depression of the mercury during a frosty period brings on a thaw: if the wind be south or south-east, the thaw will continue; if the wind be south-west, the frost will be likely to return with a rising barometer and northerly wind.

In the winter season, a rapid rise of the mercury immediately after a gale from the south-west with rain (the wind going round to north-west or north) is usually attended with clear sky and sharp white frosts.

Great depressions in the summer months are attended with storms of wind and rain with thunder and hail: cold, unseasonable weather generally succeeds the depressions.

During a period of broken cold weather in the winter months, with the wind at north or north-north-west, a sudden rise of the mercury denotes the approach of rain and a southerly wind.*

During a steady frost with the wind at north, north-east, or east, a continued slow rising of the mercury indicates snow and cloudy weather.

If the mercury rise with the wind at south-west, south, or even south-east, the temperature is generally high.

Observation does not show that *extremes of temperature* are contemporaneous with the greatest elevations and least depressions of the mercurial column.

Meteors are not prevalent during very low pressures: the *Aurora Borealis* has been noticed at all heights of the barometer. Small flashes of lightning are of frequent occurrence during stormy weather in the winter season when the mercury stands low.

Great elevations in the summer are generally attended with dry, warm weather.

Great depressions at all seasons are followed by change of wind, and by much rain.

A rising barometer with a southerly wind is usually followed by fine weather. In the summer it is dry and warm; in the winter, dry with moderate frosts. This is of rare occurrence.

When the mercury is very unsteady during calm rainy weather, it denotes that the air is in an electrical state, and that thunder will follow.

In the summer months, if a depression of two or three tenths of the mercury occur in a hot period, it is attended with rain and thunder, and succeeded by a cool atmosphere. Sometimes heavy thunder-storms take place overhead without any fall of the mercury; in this case a reduction of temperature does not usually follow.

Rain in some quantity may fall with a high pressure, provided the wind be in any of the northerly points; and when much rain falls with a steady rising barometer and the mercury attains a great elevation, a long period of fine weather usually succeeds.

If after a storm of wind and rain, the mercury remains steady at the point to which it had fallen, serene weather may

* Thaws also commonly set in during the night.

follow without a change of wind; but on the rising of the mercury, rain and a change of wind may be expected.

During a series of stormy weather the mercury is in constant agitation, falling and rising twice or thrice in the space of twenty-four hours, the wind changing alternately from south to west, and backing again to the south: this alternation of winds continues until the mercury rises to a bold elevation, when it ceases, and the weather becomes settled.

Storms of wind, especially when accompanied with much rain, produce the greatest depressions of the mercury. No storm of wind on record has blown without some rain falling, although the time of its falling and its amount have been variable: sometimes the rain has increased with the increasing storm and sinking mercury; at other times the rain has fallen suddenly at the close of the storm, or at the time of the *minimum* pressure.

No great storm ever sets in with a steady rising barometer.

As far as regards the locality of Greenwich, the most violent gusts of wind come from due south, and those next in violence from due north; in both instances the mercury remains stationary at its *minimum* point during the greatest *horizontal pressure:* the winds from these quarters are of short duration, and limited in their extent. The ordinary south-west gales will blow unremittingly for twenty-four hours, and will sweep over the whole of the British Isles.

Note.—Although a rising mercury attends a northerly wind, great depressions occur previously to a great storm coming from that quarter.

In England, the winds which blow for the greatest number of days together without intermission are the west and west-south-west: they blow chiefly during the winter months, and are the principal cause of our mild winters.

The east and east-north-east are the winds the next most prevalent. The great antagonist winds, the north and south, are the origin of our most violent storms.

The westerly winds surge mostly by night, and their average force is twice that of the easterly winds.

The easterly winds are generally calm at night, but blow with some power during the day.

On an average, sunrise and sunset are the periods of the twenty-four hours in which there is the least wind. An hour or two *after noon* is the period when the wind is the highest.

As a general rule when the wind turns against the sun, or *retrogrades* from west to south, it is attended with a falling mercury; when it goes in the *same direction* as the sun, or turns direct from west to north, the mercury rises, and there is a probability of fine weather.

It never hails in calm weather. When hail falls, it is during sudden gusts of wind, and the mercury rises while the hail is actually falling.

If the weather during harvest-time has been generally fine, and a fall of the mercury with a shower occur,—if the wind turn a few points to the north and the barometer rises above 30 inches, the weather may be expected to be fair for some days.

The finest and most beneficial state of the atmosphere, more especially as regards the health of man, is with a uniform pressure at a mean height of the barometer varying from 29·80 to 30·00.

When there is only one current of air subsisting in the atmosphere, there is seldom much variation in the height of the mercurial column. It is when two or more *strata* of the air are in motion in different directions at the same time, that great fluctuations of the mercury occur.

In high pressures, the *upper* current usually sets from the northward; in low pressures it sets from the south and south-west.

The variations of the barometer are always greater in the winter than in the summer.

In accounting for the different currents of the atmosphere it must be remarked that the great heat of the torrid zone causes a constant ascent of air over it, which passes northward and southward; while an under current of cold air flows from the poles to supply its place; the diurnal rotation of the earth combined with these currents causes the trade-winds, whose direction is from east to west: these currents would from the same causes become in the north temperate zone north-east and south-west winds, and in the south temperate zone south-east and north-west winds; but the great irregularities of the temperature from the seasons, the large tracts of ocean, and the different geographical formations of the land, subject them to interruptions, and give to every country its prevailing winds, derived from local causes. In England, the south-south-west, south-west, and west-south-west winds set in towards the end of October, and blow with their greatest strength

during November, December, and February, and are even powerful in June and July: the winds from the westerly quarters prevail in March, but they then veer more towards the north, whence they blow with great violence: in April, the east and north-east, and the west and north-west winds balance each other, and their comparative strength is nearly equal; in May, the east, north-east, and north-north-east winds preponderate; the latter blows the less frequently, but with the greatest violence; in this month the average of the winds from the westerly quarters ranges low; their average strength also decreases, with the exception of that from the west-south-west, which ranges higher than in April. In August the west and west-south-west winds prevail, but their power is moderate; the stormy winds of this month blow from the west-south-west and north-north-west. September is the calmest period of the year; in this month the north and south winds, and the east and west winds, balance each other; in January the east and west winds upon an average are nearly equal, both as regards the number of times they blow, and their average strength; the winds from the south-south-west, west-south-west, and the north-westerly quarters are more rare, but they blow with great violence. As the winds from these opposite quarters predominate, so is the character of our winters determined as to mildness or severity.

Sudden depressions of the barometer sometimes occur in weather apparently calm. It is almost an established fact that storms have a circular motion; and if, when an exhaustion or sudden diminution of the atmosphere takes place, the mercurial column happen to be in the partial vacuum or centre of motion, the air will be at rest; while the surrounding air at a greater distance from the centre will be violently agitated with a less fall of the barometer. This circular motion of the atmosphere is not confined to one spot where the storm may commence and expend its violence; but it has a progressive cycloidal movement onwards, changing constantly the situation of its centre of motion and, as it advances, enlarging its circumference, until, having traversed many hundred miles, it becomes exhausted as the air recovers its equilibrium. These great rarefactions of the atmosphere are probably the effects of electricity; they are common in their most terrific form in the Indian Ocean, on the western coast of Africa, and in the *West Indies*.

In our own climate the approach of thunder-clouds produces violent squalls of wind; and dense and highly electrified clouds will sometimes raise miniature whirlwinds as they pass overhead.

THERMOMETRIC HYPSOMETRY.

Water, and even ice, constantly give off steam or aqueous vapour at all temperatures, when exposed to the air; thus we know that if a glass of water be left in a room for some days, the whole of the water will gradually evaporate. This power of water to rise in vapour at all temperatures is called the *elastic force*, or *tension*, of aqueous vapour. It may be measured, when a small quantity of water is placed above the mercury in a barometer, by the depression which the tension of the vapour thus given off is capable of producing in the mercurial column. If we gradually heat the drops of water thus placed in the barometer, we shall notice that the column of mercury gradually sinks, and when the water is heated to the boiling point, the mercury in the barometer tube is found to stand at the same level as that in the trough—showing that *the elastic force of the vapour*, at that temperature, *is equal to the atmospheric pressure.*

Hence, *water boils when the tension of its vapour is equal to the pressure of the superincumbent column of atmosphere;* and, consequently, on the tops of mountains, where the atmospheric pressure is less than at the sea-level, water boils at a temperature below the 212° of common experience.

A simple experiment to illustrate this fact, consists in boiling water in a globular flask, into the neck of which a stop-cock is fitted. As soon as the air is expelled, the stop-cock is closed, and the flask removed from the source of heat. The boiling then ceases. But, on immersing the flask in *cold* water, the ebullition recommences briskly—owing to the *reduction of the pressure*, consequent upon the condensation of the steam—the tension of the vapour at the temperature of the water in the flask being greater than the diminished pressure.

Founded on this principle a thermometric instrument has been constructed for determining heights, by noticing the temperatures at which water boils.*

* All other liquids obey a similar law of ebullition; but as the tensions of their vapours are very different, their *boiling points* vary considerably.

Wollaston's Boiling-point Hypsometer.—This is simply a cylindrical copper vessel of small size, with or without a spirit lamp, closed at the top, in which there is a cork; and through the cork is passed a thermometer, the bulb of which descends to half an inch above a small quantity of water in the vessel. Of course there is a vent-hole for the steam at the side of the rim.

Mr. Casella has specially identified himself with thermometric hypsometry. His instrument is constructed generally on Dr. Wollaston's principle, but arranged and modified by Colonel Sykes, F.R.S., Regnault, and others, but with considerable simplification and improvement. The thermometer, strong and sensitive, with small bulb, is divided and figured on the stem, and sheltered from cold when in use by a double telescopic chamber, into which it is passed to any required depth, through a loose piece of india-rubber, which rests on the top; the chamber being filled with vapour from the boiling water beneath. The inner chamber being thus completely filled, the vapour descends into the outer chamber, and escapes by the outlet. By this means the mercury, both in the bulb and stem, is immersed in pure vapour, *whatever kind of water may be employed.* A portable leather case contains the whole, when packed for travelling.

The Alpine Hypsometer.—A still smaller apparatus on the same principle has been much used by the members of the Alpine Club, and other distinguished travellers.* It is fitted in a small tin case, in which it may be used in windy weather. Size 5½ inches long by 2½ diameter; weight, 13 ozs.; and it may be carried in the trowsers-pocket. It is used by many instead of a barometer, and by those a little experienced in its use it is often preferred, for its simplicity and certainty, to the mountain barometer.

"For the elevation of great mountain-masses," says Dr. I. H. Hooker, "and continuously elevated areas, I consider that hypsometrical results are as good as barometrical ones; for the general purposes of botanical geography, the *boiling-point thermometer* supersedes the barometer in point of practical utility, for under every advantage the transport of a glass tube full of mercury, nearly 3 feet long, and cased

* Among the rest by Baker, "Falls of the Nyansi."

in metal, is a great drawback to the unrestrained motion of the traveller."*

A convenient approximate rule has been given by Lefroy for ascertaining altitude by the boiling point of water, viz. :—

Allow for each degree below 212° Fahr. that water boils in a metal vessel, in mean state of barometer (*i.e.* a little above or below 30 inches in height)—

511 feet for first degree;
513 „ for second „
515 „ for third „ &c.

But the errors of thermometric measurements of height are always large, except in the tropics.

* "Himalayan Journals," vol. ii.

PART V.

ASTRONOMICAL INSTRUMENTS.

PRELIMINARY.

In a rudimentary work of this kind, a description of the large fixed instruments used in observatories would hardly be in its proper place, as but few persons can become practically acquainted with their use. Our descriptions will therefore be confined to such instruments as are of a portable character, and may be set up and used by private individuals for the purposes of astronomical observation, or for the most important observations in geodetical surveys. Hadley's sextant is, in fact, an instrument indispensable to the navigator and to the marine surveyor, and to this our attention will be first directed, and we shall then proceed to describe the portable transit, and altitude and azimuth instruments, with the collimator, an instrument which may be used in their adjustment, and the equatorial.

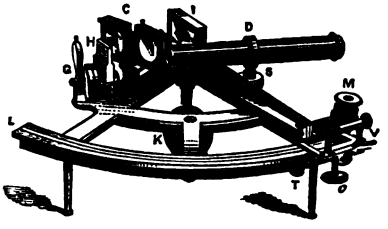
CHAPTER I.

HADLEY'S SEXTANT.

This instrument differs from the pocket sextant, already described—in its appearance, from the absence of the box in which the pocket sextant is fixed—in its size varying usually from 4 inches to 6 inches radius—and in its requiring and admitting of more perfect and minute adjustment.

L is the limb of the instrument, graduated from 0° to 140°, at every 10′ or 20′, according to the size of the instrument, and subdivided by the vernier, V, to 10″ or 20″, thus enabling us to read off angles by estimation to 5″. The limb is also graduated through a small space, called the arc of excess, on the other side of the zero point. T is the tangent screw for giving a slow motion to the index bar after it has been clamped by the screw O. M is a microscope, attached to the index bar, movable by a screw, V, so as to command a view of the vernier throughout its entire length.

I is the index glass, or first reflector, attached to, and moving with, the index bar; and H is the horizon glass, having its lower half silvered, to form the second reflector, and its upper half transparent. Four dark glasses are placed at C, any one



or more of which can be turned down between the index glass and horizon glass, to moderate the intensity of the light from any very bright object, viewed by reflection; and at G are three dark glasses, any one or more of which can be turned up, to moderate the intensity of the light from any bright object, viewed directly through the transparent part of the horizon glass. D is a ring for carrying the telescope, attached to a stem S, called the up-and-down piece, which can be raised or lowered by means of a milled-headed screw. The use of this up-and-down piece is to raise or lower the telescope, till the objects seen directly and by reflection appear of the same brightness. K is the handle by which the instrument is held.

In selecting an instrument, care must be taken that all the joints of the frame are close, without the least opening or looseness, and that all the screws act well, and remain steady, while the instrument is shaken by being carried from place

to place. All the divisions on the limb and vernier, when viewed through the microscope, must appear exceedingly fine and distinct, and the inlaid plates upon which the divisions are marked must be perfectly level with the surface of the instrument. The index, or zero, of the vernier should also be brought into exact coincidence successively with each division of the limb, till the last division upon the vernier reaches the last division upon the limb; and if the last division of the vernier do not in each case also exactly coincide with a division upon the limb, the instrument is badly graduated, and should be rejected. All the glass used in the instrument should be of the best quality, and the glasses of the reflectors should each have their faces ground and polished perfectly parallel to each other, to avoid refraction. Look, therefore, into each reflector, separately, in a very oblique direction, and observe the image of some distant object; and if the image appears clear and distinct in every part of the reflector, the glass is of good quality; but if the image appear notched, or drawn with small lines, the glass is veiny, and must be rejected. Again, if the image appears singly, and well defined about the edges, the two surfaces of the glass are truly parallel; but if the edge of the image appears misty, or separated like two images, the two surfaces are inclined to one another. The examination will be more perfect if the image be examined with a small telescope.

A plain tube and two telescopes, one showing objects inverted and the other erect, are usually supplied with the sextant. The manner of testing the telescopes has already been explained in the part of the work devoted to optical instruments. A dark glass is also supplied to fit on to the eye-end of the telescope, and a key for turning the adjusting screws.

To examine the Error arising from the Imperfection of the Dark Glasses.—Fit the dark glass to the eye-end of the telescope, and all the shades being removed, bring the reflected image of the sun into contact with its image seen directly through the unsilvered part of the horizon glass. Then remove the dark glass from the eye-end of the telescope, and setting up first each shade separately, and then their various combinations, if the two images do not in any case remain in contact, the angle through which the index must be moved to restore the contact is the error of the dark glass, or combination of dark glasses, used in the ob-

servation, and which error should be recorded for each glass and each combination of the glasses.

The adjustments of the instrument consist in setting the horizon glass perpendicular to the plane of the instrument, and in setting the line of collimation of the telescope parallel to the plane of the instrument.

To adjust the Horizon Glass.—While looking steadily at any convenient object, sweep the index slowly along the limb, and if the reflected image do not pass exactly over the direct image, but one projects laterally beyond the other, then the reflectors are not both perpendicular to the face of the limb. Now the index glass is fixed in its place by the maker, and generally remains perpendicular to the plane of the instrument, and, if it be correctly so, the horizon glass is adjusted by turning a small screw at the bottom of the frame in which it is set, till the reflected image passes exactly over the direct image.

To examine if the Index Glass be perpendicular to the Plane of the Instrument.—Bring the vernier to indicate about 45°, and look obliquely into this mirror, so as to view the sharp edge of the limb of the instrument by direct vision to the right hand, and by reflection to the left. If then the edge and its image appear as one continued arc of a circle, the index glass is correctly perpendicular to the plane of the instrument; but if the arc appears broken, the instrument must be sent to the maker to have the index glass adjusted.

To adjust the Line of Collimation.—1. Fix the telescope in its place and turn the eye-tube round, that the wires in the focus of the eye-glass may be parallel to the plane of the instrument. 2. Move the index till two objects, as the sun and moon, or the moon and a star, more than 90° distant from each other, are brought into contact at the wire of the diaphragm which is nearest the plane of the instrument. 3. Now fix the index, and altering slightly the position of the instrument, cause the objects to appear on the other wire; and if the contact still remain perfect, the line of collimation is in correct adjustment. If, however, the two objects appear to separate at the wire that is farther from the plane of the instrument, the object-end of the telescope inclines towards the plane of the instrument; but if they overlap, then the object-end of the telescope declines from the plane of the instrument. In either case, the correct ad-

justment is to be obtained by means of the two screws which fasten, to the up-and-down piece, the collar holding the telescope, tightening one screw and turning back the other, till, after a few trials, the contact remains perfect at both wires.

The instrument having been found by the preceding methods to be in perfect adjustment, set the index to zero, and if the direct and reflected images of any distant* object do not perfectly coincide, the arc through which the index has to be moved to bring them into perfect coincidence constitutes what is called the index error, which must be applied to all observed angles as a constant correction.

To determine the Index Error.—The most approved method is to measure the sun's diameter, both on the arc of the instrument, properly so called, to the left of the zero of the limb, and on the arc of excess to the right of the zero of the limb. For this purpose, firstly, clamp the index at about 30′ to the left of zero, and, looking at the sun, bring the reflected image of his upper limb into contact with the direct image of his lower limb, by turning the tangent screw, and set down the minutes and seconds denoted by the vernier; secondly, clamp the index at about 30′ to the right of zero, on the arc of excess, and, looking at the sun, bring the reflected image of his lower limb into contact with the direct image of his upper limb, by turning the tangent screw, and set down the minutes and seconds denoted by the vernier underneath the reading before set down. Then half the sum of these two readings will be the correct diameter of the sun, and *half their difference will be the index error.* When the reading on the arc of excess is the greater of the two, the index error, thus found, must be added to all the readings of the instrument; and when the reading on the arc of excess is the less, the index error must be subtracted in all cases. To obtain the index error with the greatest accuracy, it is best to repeat the above operation several times, obtaining several readings on the arc of the instrument, and the same number on the arc of excess; and the difference of the sums of the readings in the two cases, divided by the whole number of readings, will be the index error; while the sum of all the readings, divided by their number, will be the sun's diameter.

* If the distance of the object from the observer be less than a *quarter of a mile, there will be a sensible error due to parallax.* See p. 58.

EXAMPLE.

	Readings on the Arc of Instrument.			Readings on the Arc of Excess.		
	35			29	25	
	35	5		29	35	
	35	10		29	20	
	105	15		88	20	
	88	20		105	15	
No. of readings	6) 16	55	Difference.	6) 193	35	Sum.
	2	49	Index error.	32	15·8	Sun's diam.

The readings on the arc of excess being less than those on the arc of the instrument, the index error, 2′ 49″, is to be subtracted from all the readings of the instrument.

NOTE.—In taking off the readings on the arc of excess, the vernier must be read backwards; that is, the division read off on the limb being the division next to the left of the zero of the vernier, the divisions of the vernier to be added must be reckoned from the other end of the vernier, to the division coinciding with a division upon the limb; or the reading of the vernier forwards, according to the usual method, may be subtracted from 10′, the limb being divided to 10′, and the remainder added to the reading of the division upon the limb next to the left of the zero of the vernier, as before.

The manner of observing with the sextant has been already explained. when treating of the pocket sextant.

CHAPTER II.

THE TRANSIT INSTRUMENT.

THE reflecting instruments which we have just described, from their portability, and the promptitude and facility with which they may be used in all situations and upon all occasions, are most useful instruments to the surveyor. The sextant, with an artificial horizon, and a good chronometer, forms, in fact, a complete observatory, with which the latitudes and longitudes of places may be determined to a great degree of accuracy; and to the navigator a reflecting instrument is indispensable; all other instruments requiring to be supported upon a stand perfectly at rest,* while the

* In observatories the instruments are supported by stone walls, or pillars, which pass below the floors, without touching them, or any

sextant and similar instruments are held in the hand, and perform their duty well on the deck of a rolling ship. In permanent observatories, however, the capital angular instruments are placed permanently in the plane of the meridian, and the measurements sought for by their aid are the exact times at which the observed objects pass the meridian, and their angular altitudes or zenith distances when upon the meridian. The instrument with which the first of these measurements are obtained, is called a *transit instrument, transit telescope*, or merely a *transit*. Transits of portable dimensions, besides their use in small or temporary observatories, are also found serviceable to the surveyor, for determining, with the greatest possible accuracy, the true north point, and thence setting out a line in any required direction; and to the scientific traveller, for determining the longitude of any place from astronomical observations, and for adjusting his time-keepers with greater accuracy than can be obtained by his sextant. The annexed figure represents a portable transit.

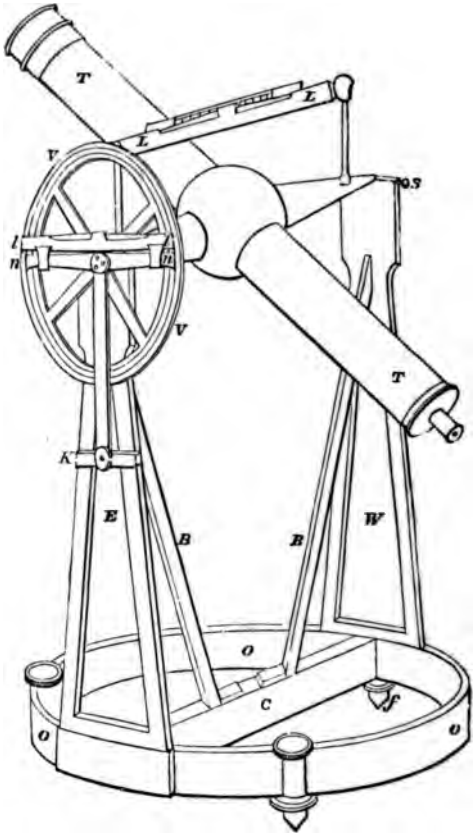
T T is a telescope formed of two parts, connected by a spherical centre-piece, into which are fitted the larger ends of two cones, the common axis of which is placed at right angles to the axis of the telescope, to serve as the horizontal axis of the instrument. The two small ends of these cones are ground into two perfectly equal cylinders, called *pivots*. The pivots rests upon angular bearings or Y's. The Y's are supported upon the standards E and W, of which E may be called the eastern, and W the western standard; and one of the Y's is fixed in a horizontal groove on the western standard, so that, by means of the screw S, one end of the axis may be pushed a little forwards or backwards, and a small motion in azimuth be thus communicated to the telescope.* The standards, E and W, are fixed by screws upon a brass circle

part of the building, and are consequently independent of any tremor communicated to the floor or walls of the buildings. It was considered that the passage of a railway through Greenwich Park would impair the observations at the Royal Observatory, by communicating a tremor to the ground.

* The large transits in permanent observatories have their Y's placed in two dove-tailed grooves, one horizontal, and the other vertical. By means of the latter one end of the axis may be raised or depressed; but in the portable transit the same object is attained by turning one of the foot screws upon which the entire instrument rests.

o o, and steadied by oblique braces, B, B, which spring from the cross-piece C.

On one end of the axis is fixed, so as to revolve with the axis, a vertical circle V V; and a double index bar.



furnished with a spirit level, *l l*, to set it horizontal, carries two verniers, *n n*, adapted to the vertical circle, and showing the angle of elevation of the telescope. The index bar is fixed in its position by the clamping screw

K, and can be fixed upon either the eastern or western standard, at pleasure, while the telescope, with its attached circle, can also be lifted out of the Y's, and have its position reversed in them. The pivot which does not carry the vertical circle is pierced, and allows the light from a lamp to fall upon a plane speculum, fixed in the spherical centre piece on the axis of the telescope, and inclined to this axis at an angle of 45°. The light is thus thrown directly down the telescope, and illuminates the wires of the diaphragm, placed in the principal focus of the telescope. Of these wires, one is horizontal; and a vertical wire, intersecting it in the centre of the field of view, gives, by its intersection with it, the collimating point. There are also other vertical wires, arranged in pairs, equidistant from the central vertical wire, so that we have either three, five, or seven vertical wires, the most common number being five. The lamp has a contrivance for regulating the quantity of light thrown into the telescope, by turning a screw, so that the light from a small star may not be overpowered by the superior light of the lamp.

The requisites of a good instrument are—1stly, that the telescope be of the best quality, which is to be tested by the methods already given (vol. ii.); 2ndly, that the feet-screws act well and remain steady; 3rdly, that all the screws, by which the instrument is put together, are turned home, and remain so, after the instrument has been shaken by carriage; 4thly, that the length of the axis be just sufficient to reach from one Y to the other, without either friction or liberty; 5thly, that the lamp be held so as not to require adjustment for position; 6thly, that the screws for adjustment of the diaphragm and Y's be competent to give security of position to the parts adjusted by them; 7thly, that the metallic parts be free from flaws in casting, and that the pivots be formed of hard bell-metal, and incapable of rusting.

ADJUSTMENTS.

The principal adjustments of the transit are three:—

1st. To make the axis on which the telescope moves horizontal.
2nd. To make the line of collimation move in a great vertical circle, by setting it perpendicular to the horizontal axis.
3rd. To make it move in that vertical circle, which is the meridian.

To make the Axis Horizontal.—Apply to the pivots the large level, L L, which is supplied with the instrument for

this purpose, and is constructed either to stand upon the pivots, in which case it is called a striding level, or of the form shown at page 10, in which case it is suspended from the pivots, and is called a hanging level. Bring the air-bubble to the centre of its run, by turning the foot screw *f*. Turn the level end for end, and if the air-bubble retains its position, the axis is horizontal; but if not, it must be brought back, half by the foot-screw, *f*, and half by turning the small screw at one end of the level. Repeat the operation till the bubble retains the same position in both positions of the level, and the axis will be horizontal.

To adjust the Line of Collimation in Azimuth.—Direct the telescope to some distant, small, and well-defined object, and bisect it by one extremity of the middle vertical wire, giving the telescope the azimuthal motion necessary for this purpose by turning the screw s. By elevating or depressing the telescope, examine whether the object is bisected by every part of the middle vertical wire; and if not, loosen the screws which hold the eye-end of the telescope in its place, and turn the end round very carefully till the error is moved. Lift the transit off the Y's, and reverse it, so that the end of the axis which was upon the eastern Y may now be upon the western, and *vice versâ;* and, if the object is still bisected by the central vertical wire, the collimation in azimuth is perfect, but if not, move the centre of the cross wires half way towards the object, by turning the small screws which hold the diaphragm, and if this half distance has been correctly estimated, the adjustment will be accomplished. Again bisect the object by the centre of the cross wires by turning the azimuthal screw s, and repeat the operation till the object is bisected by the centre of the cross wires in both positions of the instrument, and the adjustment will be known to be perfect.*

To adjust the Transit to the Meridian.—The line of collimation by reason of the previous adjustment describes a vertical circle, and, therefore, bisects the zenith, which is one point in the meridian; if, then, we can make it also bisect another point in the meridian, it will move entirely in the

* The horizontal motion given to the Y by the azimuthal screw s, forms, evidently, no part of the adjustment for collimation, but only enables us to examine if the adjustment has been made with sufficient exactness.

meridian. Compute from the tables in the Nautical Almanack the time of Polaris coming to the meridian, and at the computed time bisect the star by the middle vertical wire, and the transit will be very nearly adjusted to the meridian.

To make the great vertical circle described by the line of collimation more nearly coincident with the meridian, let the intervals between the successive passages of Polaris across the meridian be observed, as indicated by the instrument. Then, if the interval between the inferior and superior passage be equal to the interval between the superior and inferior, the adjustment to the meridian is perfect; but if the interval between the inferior and superior passage be less than the interval between the superior and inferior, the circle described by the line of collimation deviates to the eastward of the true meridian, from the zenith to the north point of the horizon, and to the westward, from the zenith to the south point of the horizon; while if the interval between the inferior and superior passage be the greater, the deviation is in the contrary directions.

Let δ be the observed difference of the intervals from twelve hours, or half the difference between the two intervals, in seconds, π the polar distance of the star Polaris, and L the latitude of the place; then, z representing, in time, the deviation from the meridian, the value of z will be given by the logarithmic formula,

$$\log. z = \log. \frac{\delta}{2} + \log. \sec. L + \log. \tan. \pi - 20$$

EXAMPLE.

Place of observation, Cambridge, latitude 52° 12′ 36″.
Polar distance of Polaris, 1° 39″ 25″·05.
Difference of intervals from 12^h, 7^m, $22^s = 442^s$.

$\frac{\delta}{2} = 221$	.....log.	= 2·3443923
$L = 52°\ 12'\ 36''$	.....log. sec.	= 10·2127030
$\pi = 1°\ 39'\ 25''·05$	...log. tan.	= 8·4513064
$z = 10^s·195$	.....log.	= 21·0084017

To determine the value of a revolution of the azimuthal screw s, the time* of passage of an equatorial star across the middle vertical wire must be noted one day; and then,

* The time here spoken of, and throughout the description of this instrument, unless otherwise expressly stated, is sidereal, and not *mean time.*

turning the screw, S, once round, the time of passage must be noted again the next day; and the difference of these times will be the equatorial value in time of a revolution of the screw. Suppose the difference thus observed to amount to two seconds, then the equatorial value of one complete revolution of the screw, S, is two seconds, and the value of the motion of the adjusting screw, thus obtained, must be reduced to the horizon, by increasing it in the ratio of radius to cosine of latitude, and may then be applied to correct the error of deviation, as found above.

A second method, founded on the same principles as the preceding, consists in observing the polar star, and another star, which crosses the meridian near the zenith of the place of observation. The time of passage of such a star, Capella, for instance, when near its superior transit, across the middle wire of the telescope, will differ but very little from the time of passing the true meridian, if the deviation of the instrument from the meridian be but small. Assume the two times to agree exactly, and the difference between the times of superior transit of Capella and Polaris will be the difference of the observed right ascensions of these two stars. From this difference subtract the difference of the computed, or catalogued, right ascensions of the two stars, and call the result D; and the deviation will be given by the formula,

$$\log. Z = \log. D + \log. \sin. \pi + \log. \sec. (L + \pi);$$

π being the polar distance of Polaris, and L the latitude of the place of observation. From Capella not having been exactly on the meridian, when on the middle vertical wire, the value of D, as above obtained, is only an approximation to the error of the observed right ascension of Polaris, and the deviation computed from it will be only approximately correct; but, by repeating the operation, the adjustment may be completely perfected.

D is actually the value of the sum of the errors of the observed right ascensions of Capella and Polaris, and hence the value of Z will be correctly given, by so considering it, instead of supposing as above, that this error for Capella is zero. The true deviation then is given by the formula,

$$\log. Z = \log. D + \log. \sin. \pi + \log. \sin. \pi' + \log. \operatorname{cosec}. (\pi' - \pi) + \log. \sec. L;$$

π' being the polar distance of Capella.

Using this last formula, the method may be applied to

Polaris, and any star distant from the pole, or to any two stars differing from each other not less than 40° in declination. If, however, the transit of one star is observed above, and of the other below the pole, the formula will be

$$\log. z = \log. D + \log. \sin. \pi + \log. \sin. \pi' + \log. \operatorname{cosec}. (\pi' + \pi) + \log. \sec. L.$$

Considerable advantage may be obtained by selecting two stars that differ but little in right ascension, as there is then the less probability of error from a change in the rate of the clock, or in the position of the instrument, on which account such methods are to be preferred in temporary observatories, where the stability of the instrument is not to be depended upon for any length of time.

In all the preceding formulæ, the deviation from the meridian is given in time; but, to convert it into angular measure, if desirable, we have only to multiply by 15, and the seconds of time will be converted into seconds of a degree.

When the instrument is, by any of the methods explained above, brought into the meridian, a distant mark may be set up in the plane of the meridian, by which the adjustment to the meridian may afterwards be tested.

METHOD OF OBSERVING WITH THE TRANSIT.

The adjustments having been completed, in making observations with the instrument, the instant of a star's passing the middle vertical wire will be the time of the star's transit; but the time of the star's passing all the five wires must be noted, and the mean of the times, taken as the time of transit, will be a more accurate result than the time observed at the middle wire only.

When the sun is the object observed, the time of the centre of his disc passing the middle wire is the time of transit; but, as it would be impossible to estimate the centre with accuracy, the time of both his limbs coming into contact with each wire in succession is to be noted, and a mean of all these times will be the time of transit required. This mean may be conveniently taken, by writing the observed times of contact of the first and second limbs underneath each other in the reverse order, when the sums of each pair will be nearly equal.*

* This is Dr. Pearson's method.

EXAMPLE.

	s.	s.	h. m. s.	s.	s.	
1826, Sept. 23	20·4	38·7	11 58 57·0	15·5	33·7	⊙ 1 Limb.
	42·3	24·0	12 1 5·7	47·2	28·7	⊙ 2 Limb.
	2·7	2·7	24 0 2·7	2·7	2·4	The sum = 13·2

The time of either limb passing the centre wire is recorded in full, but for the other wires, the seconds only are recorded, as the sums of the several pairs only differ by decimals of a second. Half the sum of the times at the middle gives, then, the correct time of transit as far as the seconds, and the decimals are found by removing the decimal point one place to the left in the sum 13·2, which is equivalent to dividing by 10. Then the time of transit, or mean of observations in the above example, is $12^h\ 0^m\ 1^s{\cdot}32$. This example is taken from observations made with a large transit; and if with a smaller instrument the sums of the several pairs of observations should differ by more than a second, it will be necessary to take the sums of both figures of the seconds, and the division by 10, performed as above, will give the last figure of the seconds, as well as the decimals.

In taking transits of the moon the luminous edge alone can be observed, from which the time of transit of the centre must be deduced by the aid of Lunar tables.

In observing the larger planets, one limb may be observed at the first, third, and fifth wires, and the other at the second and fourth, and the mean of these observations will give the transit of the planet's centre.

It will sometimes happen that from the state of weather, or from some other cause, a heavenly body may not have been observed at all the wires; but, if the declination of the body be known, an observation at any one of the wires may be reduced to the central wire, so as to give the time of transit, as deduced from this observation. If an observation be obtained at more than one wire, the mean of the times of passing the centre, as deduced from each wire observed, is to be taken as the time of transit. The reduction to the centre wire is given by the formula,

$$R = V \operatorname{cosec.} \pi,$$

$$\textit{or } \log. R = \log. V + \log. \operatorname{cosec.} \pi;$$

in which R represents the reduction, π the polar distance of the body observed, and V the equatorial interval from the wire at which the observation has been made to the central wire. The equatorial intervals for each side wire must, therefore, be carefully observed, and tabulated for the purpose of this reduction. The formula $R = V \operatorname{cosec.} \pi$ is only an approximate value of the reduction, and with large instruments capable of giving results within 0″·05, a further correction is necessary for bodies within 10° of the pole. The whole reduction in this case is given by the formula,

$$R' = \frac{1}{15} \sin.^{-1} (\operatorname{cosec.} \pi \sin. 15\ V).$$

The time of any star's passage from one of the side wires to the centre wire being observed, the equatorial interval from that wire to the centre is obtained by multiplying the observed interval by the sine of the star's polar distance; and the equatorial intervals being deduced in this manner from a great many stars, the mean of the results may be considered as very correct values of the equatorial intervals required. No star very near the pole should, however, be taken for this purpose.

USE OF THE PORTABLE TRANSIT.

The large transits in permanent observatories are used to obtain, with the greatest possible accuracy, the right ascensions of the heavenly bodies, from which, and the meridian altitudes observed by a mural circle, an instrument consisting of a telescope attached to a large circle, and placed in the plane of the meridian, nearly all the data necessary for every astronomical computation are obtained. For such purposes the small portable transit is not adapted; but it is competent to determine the time to an accuracy of half a second, to determine the longitude by observations of the moon and moon culminating stars, and to determine the latitude by placing it at right angles to the meridian, or in the plane of the prime vertical.*

The transit of the sun's centre gives the apparent noon at the place of observation, and the mean time at apparent noon is found by subtracting or adding the equation of time, as

* The prime vertical is the great circle which passes through the zenith and the east and west points of the horizon.

found in the Nautical Almanack, to 24 hours.* The difference between the mean time, thus found, and the time of the sun's transit, as shown by a clock or chronometer, is the error of the clock or chronometer for mean time at the place of observation.

The time shown by a sidereal clock, when any heavenly body crosses the meridian, should coincide with the right ascension of that body, as given in the Nautical Almanack. The differencebetween the time shown by the sidereal clock, at the transit, and the right ascension of the body, taken from the almanack, will, therefore, be the error of the clock, +, or too fast, when the clock time is greater than the right ascension, —, or too slow, when it is less.

CHAPTER III.

THE PORTABLE ALTITUDE AND AZIMUTH INSTRUMENT.

The bending of an unbraced telescope renders it unfit for the determination of altitudes; but by placing the telescope between two circles braced together, an instrument may be formed capable of observing both the meridian altitudes and times of transit of the heavenly bodies. The increased weight of the instrument, however, must now be prevented from producing flexure in the horizontal axis, and this has been very ingeniously accomplished by Troughton. By mounting the transit and altitude instrument, as Troughton's transit-circle may be called, upon a horizontal plate or circle, having an azimuthal motion round a vertical axis, an instrument is formed by which observations may be made either in or out of the meridian. When constructed of a portable size, the altitude and azimuth instrument may also be used in important surveying operations; for, in fact, it may be considered as a rather large theodolite of superior construction.

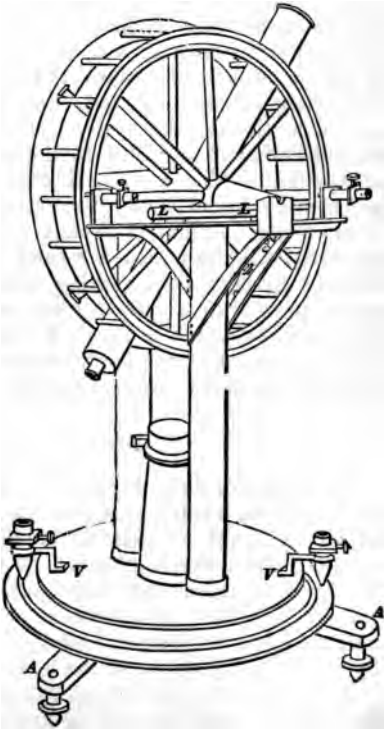
The altitude and azimuth instrument may be considered

* The astronomical day commences at noon, and contains 24 hours, the hours after midnight being called 13, 14, &c., and the day ends at the next noon. The equation of time is given in the Nautical Almanack for apparent noon at the meridian of Greenwich, and the correction to give the equation of time at any other meridian will be found by multiplying the difference for one hour, as given in the almanack, by the longitude of the place, estimated in time.

as consisting of three parts: 1, the tripod carrying the vertical axis about which the instrument turns; 2, the horizontal revolving plate carrying the vertical pillars, with their appendages; and 3, the vertical circles with the telescope.

The tripod, A A, is supported by three foot-screws, by which the vertical axis is brought into adjustment, and carries the lower horizontal plate, which is graduated to show the azimuths, or horizontal angles. The vertical axis is a solid metallic cone rising from the centre of the tripod to a height about equal to the radius of the horizontal circle.

To point out the graduation, upon the lower horizontal plate, or azimuth circle, the upper horizontal plate, or horizontal revolving plate, v v, carries an index, which denotes nearly the angle to be read off. The graduations upon the azimuth circle, as well as upon the vertical circle, are subdivided by reading microscopes, the construction and adjustments of which we shall presently explain. The reading microscopes of the azimuth circle are attached to the revolving plate, v v, which also carries two upright pillars. From the centre of the upper horizontal plate, v v, rises a hollow brass cone which just fits over, and moves smoothly upon the solid metallic vertical axis rising from the tripod stand. A horizontal brace connects the two upright pillars with one another and with the



top of the hollow brass cone, and keeps the pillars firm, and parallel to one another. On the top of each pillar a gibbet piece is fixed, projecting beyond the pillar, and upon the extreme ends of these pieces are carried the Y's for supporting the pivots of the horizontal or transit axis. The Y's are each capable of being raised or lowered by turning a milled-headed screw. The top of one of the pillars carries a cross-piece, for supporting the two reading microscopes of the vertical circle; and to this cross-piece is attached the level, L L, by which the adjustment of the vertical axis is denoted.

The third portion of the instrument consists of the vertical circle and its telescope. This circle consists of two limbs firmly braced together, and preventing any tendency to flexure in the tube of the telescope, by affording it support at the opposite ends of a diameter. One of the limbs only is graduated, and the graduated side is called the face of the instrument, and the clamp and tangent screw, for giving a slow motion to the vertical circle, act upon the ungraduated limb, and are fixed to the vertical pillar on the side of that limb. The horizontal axis, which supports the telescope and vertical circle, is constructed exactly as the axis of the transit instrument already described; but, as it might press too heavily on the Y's from the increased load of the vertical circle, a spiral spring, fixed in the body of each pillar, presses up a friction roller against the conical axis with a force which is nearly a counterpoise to its weight. The adjustment of the horizontal axis is denoted by a striding level, as in the portable transit already described.

ADJUSTMENT.

Adjustments of the Vertical Axis.—Turn the instrument round till the level, L L, is over two of the foot-screws, and adjust the level, so that its bubble may retain the same position when the instrument is turned half round, and the level is again over the same foot-screws, but in the reverse position. The error at each trial is corrected, as nearly as can be judged, half by the foot-screws, and half by the adjusting screw of the level itself.

Next turn the instrument round 90^{c} in azimuth, so that the level, L L, may be at right angles to its former positions

and bring the bubble to the same position as before, by turning the third foot-screw. Repeat the whole operation till the result is satisfactory.

Adjustment of the Horizontal Axis.—This adjustment is performed in the same manner as already described for the transit instrument (p. 135), with the single exception that one end of the axis is to be raised or lowered, if necessary, by the screw acting upon its Y, and not by moving a foot-screw, which would derange the previous adjustment.

Adjustment of the Circle to its Reading Microscopes.—This is performed by raising or lowering both the Y's equally, so as not to derange the previous adjustment, till the microscopes are directed to opposite points in its horizontal diameter.

Adjustment of Collimation in Azimuth.—Instead of taking the axis out of its bearings and turning it end for end, the whole instrument is turned round in azimuth; but in all other respects the method of performing this adjustment is the same as that already described for the transit instrument (p. 136).

Adjustment of Collimation in Altitude.—Point the telescope to a very distant object, or star, and, bisecting it by the cross wires, read off the angle upon the vertical circle denoted by the reading microscopes. Turn the instrument half round in azimuth, and, again bisecting the same object by the cross wires, read off the angle. One of these readings will be an altitude, and the other a zenith distance,* and their sum, therefore, when there is no error of collimation in altitude, will be 90°. If the sum is not 90°, half its difference from 90° will be the error of collimation in altitude, and this error being added to, or subtracted from, the observed angles, according as the sum of the readings is less or greater than 90°, will give the true zenith distance and altitude. The error of collimation in altitude may then be corrected by adjusting the microscopes to read the true zenith distance and altitude thus found, while the object is bisected by the cross wires of the telescope. The error of collimation of this and other astronomical instruments may also be found, or corrected, by the collimator.

* Both the horizontal and vertical circles are usually divided alike into four quadrants, and each quadrant graduated from 0° to 90°, proceeding in the same direction all round the circles.

METHOD OF OBSERVING WITH THE ALTITUDE AND AZIMUTH INSTRUMENT.

In using the altitude and azimuth instrument for astronomical purposes double observations should always be made, with the face first to the east, and then to the west, or *vice versâ*, or several observations may be made with the face to the east, and as many with the face to the west, and the mean of the results, reduced to the meridian, taken as the true results. The place for a meridian mark may be determined by the methods already explained when describing the transit instrument, or by observing the readings of the azimuthal circle, or noting the times when any celestial object has equal altitudes. Since the diaphragm of the telescope is furnished not only with the central horizontal wire, but with other horizontal wires at equal distances above and below it, so that there may be altogether either three, or five, or seven horizontal wires, the azimuths and times may be notified when the object observed is bisected by each of these wires. If a fixed star be the object observed, the mean of the times will give the time of the star's passing the meridian, and the mean of the azimuths will give the reading of the azimuth circle when the star was on the meridian, or the correction to be applied to the readings of the azimuth circle to give the true azimuths. If the sun be the body observed, a correction is necessary on account of the change of his declination during the intervals between the observations.

The correction for the time, as deduced from a pair of equal altitudes of the sun, is given by the formula—

$$\text{Correction} = \frac{\delta}{720} \times \frac{\frac{t}{2}}{\sin. 15^\circ . \frac{t}{2}} (\tan. \text{D} \times \cos. 15^\circ . \frac{t}{2} - \tan. \text{L})$$

in which δ represents the variation in the sun's declination from the noon of the day preceding the observations to the noon of the day succeeding;

t represents the interval between the observations expressed in hours and decimals of an hour;

D represents the sun's declination at noon on the day on which the observations are made;

L represents the latitude of the place.

δ is to be reckoned positive when the sun's declination is increasing, and negative when it is decreasing.

The correction for azimuth is given by the formula—

$$\text{Correction} = \tfrac{1}{2}\,(\text{D}' - \text{D})\ \text{sec. lat. cosec.}\ \frac{15}{2}\,(\text{T}' - \text{T}).$$

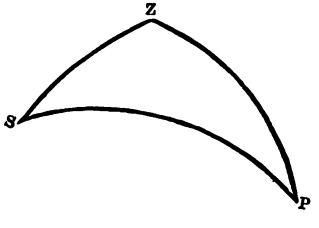
in which D′ — D represents the change of the sun's declination, and T′ — T represents the interval in time, } between the observations.

When the sun is advancing towards the north pole, this correction will carry the middle point towards the west of the approximate south point; but when he is approaching the south pole, it will carry the same point towards the east, and must be applied accordingly.

USE OF THE ALTITUDE AND AZIMUTH INSTRUMENT.

The altitude and azimuth instrument being adapted to observe the heavenly bodies in any part of the visible expanse of the heavens, its powers may be applied at any time, to determine the data from which the time, the latitude of the place of observation, or the declination of the body observed may be at once determined. We subjoin some of the formulæ, adapted to logarithmic computation, connecting the parts of what may be called the *astronomical triangle*, of which the angular points are—the pole, P; the zenith, Z and the apparent place of the body observed, S.

Let P Z, the colatitude of the place, be represented by λ
P S, the polar distance of the body observed ..... π
Z S, the zenith distance of the body observed ... z
Z P S, the hour angle from the meridian..... h
P Z S, the azimuthal angle ..... a



Then we have the following formulæ for determining the time, the latitude, and the declination of the body observed.

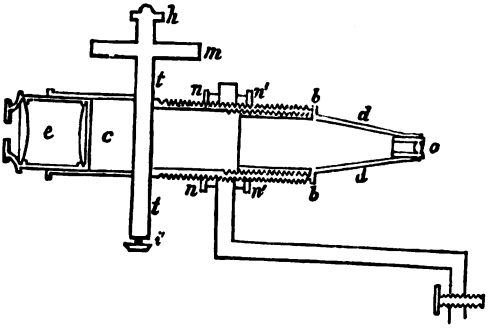
No.	Given.	Required.	Auxiliary Angles.	Formulæ.
1	z, π, λ	h	.....	$\tan \frac{1}{2} h = \sqrt{\frac{\sin \frac{1}{2}(z+\pi-\lambda) \cdot \sin \frac{1}{2}(z+\lambda-\pi)}{\sin \frac{1}{2}(z+\pi+\lambda) \cdot \sin \frac{1}{2}(\pi+\lambda-z)}}$
2	π, λ, a	h	$\tan \phi = \frac{\cot a}{\cos \lambda}$	$\cos (h \sim \phi) = \frac{\cot \pi \cos \phi}{\cot \lambda}$
3	z, λ, a	h	$\cot \phi = \frac{\cot z}{\cos a}$	$\cot h = \frac{\cot a \sin (\lambda - \phi)}{\sin \phi}$
4	z, π, a	h	.....	$\sin h = \frac{\sin z \sin a}{\sin \pi}$
5	z, π, a	λ	$\tan \phi = \cos a \tan z$	$\cos (\lambda \sim \phi) = \frac{\cos \pi \cos \phi}{\cos z}$
6	z, π, h	λ	$\tan \phi = \cos h \tan \pi$	$\cos (\lambda \sim \phi) = \frac{\cos z \cos \phi}{\cos \pi}$
7	z, a, h	λ	$\cot \phi = \frac{\cot z}{\cos a}$	$\sin (\lambda - \phi) = \frac{\cot h \sin \phi}{\cot a}$
8	π, a, h	λ	$\cot \phi = \frac{\cot \pi}{\cos h}$	$\sin (\lambda - \phi) = \frac{\cot a \sin \phi}{\cot h}$
9	z, λ, a	π	$\tan \phi = \cos a \tan z$	$\cos \pi = \frac{\cos z \cos (\lambda \sim \phi)}{\cos \phi}$
10	z, λ, h	π	$\tan \phi = \cos h \tan \lambda$	$\cos (\pi \sim \phi) = \frac{\cos z \cos \phi}{\cos \lambda}$
11	z, a, h	π	.....	$\sin \pi = \frac{\sin a \sin z}{\sin h}$
12	λ, a, h	π	$\tan \phi = \frac{\cot a}{\cos \lambda}$	$\cot \pi = \frac{\cot \lambda \cos (h \sim \phi)}{\cos \phi}$

CHAPTER IV.

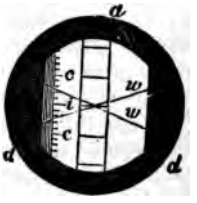
SUBSIDIARY INSTRUMENTS.

THE READING MICROSCOPE.

THE first of the annexed figures represents a longitudinal section of this instrument, and the second represents the field of view, showing the magnified divisions of the limb of



the instrument to which the microscope is applied, and the diaphragm, *d d*, of the microscope, with its comb, *c c*, and cross wires, *w w*. The diaphragm is contained in the box *t t*, and consists of two parts, moving one over the other: the comb, *c c*, which is moved by the screw, *i*, at the bottom of the box, for the purpose of adjustment; and the cross wires *w w*, and index *i*, which are moved over the comb and the magnified image of the limb, by turning the milled head *h*. The micrometer head, *m*, is attached by friction to the screw turned by the milled head, so that by holding fast the milled head, the micrometer head can be turned round for adjustment.



e is the eye-piece, which slides with friction into the cell *c*, so as to produce distinct vision of the spider's lines of the micrometer. The object-glass, *o*, is held by a conical piece, *d d*, which screws farther into or out of the body of the

instrument, so as to produce distinct vision of the divided limb to be read by the microscope, and, when adjusted, is held firmly in its place by the nut *b b*. The microscope screws into a collar, so as to be capable of adjustment with respect to its distance from the divided limb, and, when so adjusted, is held firmly in its place by the nuts *n n*, *n′ n′*.

Adjustments of the Reading Microscope.—Screw the object-glass home. Insert the body of the microscope into the collar destined to receive it, and screw home the nuts *n n* and *n′ n′*. Make the diaphragm and spider-lines visible distinctly, by putting the eye-piece, *e*, the proper depth into the cell *c*. Then make the graduated limb also distinctly visible, without parallax, by turning the nuts, *n n*, and *n′ n′*, unscrewing one, and screwing up the other, till the desired end is attained.

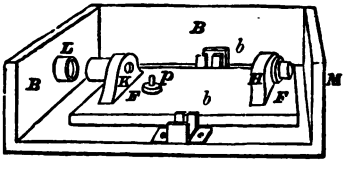
Now bring the point of intersection of the spider-lines upon a stroke of the limb, and turn the micrometer head, *m*, to zero; then, turning the screw *h*, through five revolutions, if the point of intersection of the spider-lines has not moved over the whole of one of the divided spaces on the limb, the object lens must be screwed up, to diminish the power, by turning the cone *d d*; and if it has moved over more than one of the divided spaces, it must be unscrewed to increase the power, and then altering the position of the microscope, by turning the nuts *n n* and *n′ n′* till distinct vision of the limb is again obtained, the measure of the space moved over by five revolutions of the screw must be repeated as before. When, after repeated trials, the result is satisfactory, the three nuts *n n*, *n′ n′*, and *b b*, must be screwed tight home to render the adjustment permanent.

When the microscope has been thus adjusted for distance, the zero of the divisions on the limb must be brought to the point of intersection of the spider-lines, and the divided head, *m*, turned, till its zero is pointed to by its index, and then, if the zero on the comb, *c c*, be not covered exactly by the index *i*, the comb must be moved by turning the screw *i′*, which enters the bottom of the micrometer box, till its zero is covered by the index pin. The adjustments of the reading microscope will now be perfect; and the graduated limb to be read by it, being divided at every five minutes, the degree and nearest five minutes of an observed angle will be shown by the pointer or index to this graduated limb; while the number of complete revolutions, and the

parts of a revolution of the screw *h*, in the order of the numbers upon the micrometer head, *m*, required, to bring the point of intersection of the spider-lines upon a division of the graduated limb, will be the number of minutes and seconds, respectively, to be added to the degrees and minutes shown by the index of the circle. The complete revolutions, or minutes, to be added, are shown by the number of teeth the index, *i*, has passed over from zero, and the parts of a revolution, or seconds and tenths to be added, are pointed out upon the micrometer head, *m*, by its index.

THE COLLIMATOR.

B B is a rectangular mahogany box, partly filled with mercury. F F is a float of cast-iron, partly immersed in the mercury. *b*, *b* are two iron bearing pieces, screwed to the bottom of the box by short iron screws; and each of these pieces has two vertical plates turned up, the inner one of which has a longitudinal slit in it, into which slits iron pivots, screwed into the sides of the float, are admitted. The use of these parts is to keep the sides of the float parallel to the sides of the box, and at an inch, or more, from contact with any part of the box, that the mercury may assume a flat surface. H and K are two holding pieces of metal cast along with the float, and are perforated, to receive each a socket. The socket at H receives an achromatic object-glass, and is adjustable by a screw for its focal distance, and the socket at K holds two cross wires; while another socket, let into the end of the box at L, carries a lense forming an eye-piece; so that the collimator is, in fact, an astronomical telescope, with a system of cross wires in the common focus of the object-glass and eye-lens. The inclination, as compared with the surface of the fluid, of the optical axis of this telescope, or of the line joining the centre of the object-glass and the intersection of the cross wires, can be modified by the addition of perforated pieces of iron, held steady by the vertical pin P,



and by their weight depressing the end of the float. The mercury must be as pure as can be obtained, and particles of dust must be constantly excluded by a lid that covers

over the top of the box. At M is a circular hole, closed when the instrument is not in use, through which the telescope, of which the error of collimation is sought, is to be directed; and a lamp is placed behind the eye-lens at L. to illuminate the cross wires.

Use of the Collimator with an Altitude and Azimuth Instrument.—Place the collimator in the plane of the meridian on the south side of the observatory, and direct it so that the cross wires of the telescope of the altitude and azimuth instrument may be seen through it, in the centre of the field of view; then also will the cross wires of the collimator be seen through the telescope, in the centre of its field of view. Read off the altitude of the cross wires of the collimator, and then, turning the instrument half round in azimuth, observe again the cross wires of the collimator and read off the angle upon the vertical limb, which will now be a zenith distance. The difference between the sum of these readings and 90°, is the correction which is to be applied to the altitudes and zenith distances observed with the instrument.

Example.—The sun's meridian altitude had been observed on the 20th December, 1826, and the following determination of the error was made immediately after the observations were finished; viz.:—

Before reversion the apparent altitude of the cross wires was	0°	1′	2″·33
After reversion the apparent zenith distance of the cross wires was	89	58	10 ·33
Sum	89	59	12 ·66
Defect from 90° . . .			47 ·33
Correction of errors of collimation, &c. . .			23 ·66
Altitude of cross wires corrected $= \left\{ \begin{matrix} 1' \; 2''\cdot33 \\ + \; 23\cdot66 \end{matrix} \right\} =$		1	26 ·00
Zenith distance . . $= \left\{ \begin{matrix} 89^\circ \; 58' \; 10''\cdot33 \\ + \; 23\cdot66 \end{matrix} \right\} =$	89	58	34 ·00
	90	0	0 ·00

The collimator may also be used for a meridian mark with the transit instrument. When used with a circle for measuring altitudes and zenith distances, which has no motion in azimuth, the collimator must be moved from the north to the south side of the observatory, and the mean of the observations in each of these two positions will give the correction for the errors of collimation, &c., as above.

CHAPTER V.

THE EQUATORIAL.

THE position of a body in the heavens is determined by its *right ascension* and *declination*, or its *right ascension* and *polar distance*, the polar distance being the complement of the declination. The right ascension is determined by the time of transit of the body over the meridian of the place of observation, being, in fact, identical with the sidereal time of this transit, and, consequently, equal to the mean solar time of the transit $\pm$ the equation of time $+$ the right ascension of the sun. The polar distance is also most simply and accurately determined from the observed altitude of the body when it crosses the meridian, being equal to the co-latitude plus the meridian zenith distance, when the observed body and the pole are on opposite sides of the zenith, and to the co-latitude minus the zenith distance, when the body is between the zenith and the pole. The formulæ at page 148 show how the hour angle and polar distance may be computed from observations made out of the meridian with the altitude and azimuth instrument, and from the hour angle the time of transit over the meridian, and, consequently, the right ascension is known.

However, neither the transit instrument, nor the altitude and azimuth instrument, is adapted for a prolonged view of a heavenly body; the transit being adjusted to the meridian, the object observed passes rapidly across and out of the field of view, and though by combined motion round the horizontal and vertical axes, the object may be followed with the telescope of the altitude and azimuth instrument, the operation is both inconvenient and imperfect, since it is impracticable so to combine the motions, as to keep the object in the same part of the field of view.

The equatorial supplies the means of prolonging an observation of a heavenly body to an unlimited extent; it also points out at once the right ascension and declination of an observed body; or can, without any computation, be directed to a celestial object, whose position is given, by merely setting the *verniers or microscopes* to read its known right ascension *and declination.*

The frontispiece to this volume represents a very elegan

and simple form of the equatorial. The instrument is mounted on a strong cast-iron pillar, P, which carries the bearings for the polar axis, A, with adjustments for setting it parallel to the earth's axis. The declination axis, B, revolves in a collar, which is fitted into a cast-iron socket, bolted on to the polar axis. The telescope, T, is fixed at right angles to one end of the declination axis, and balanced by the counterpoise, W, at the other end of the axis; and on this axis is the declination circle D. The polar axis carries the right ascension circle H, and can either be moved round by the hand, to set it to direct the telescope to any desired object, or made to revolve by the driving-wheel *w*, connected with a clock, the rate of which is governed by balls and fans, so as to have a continuous motion, instead of the intermittent motion of the ordinary time-keepers. The telescope has a fine adjustment for declination, worked by the handle *h*, and the intervention of a Hook's joint, carries a finder, F, for the more easy discovery of an object, and has a diagonal eye-piece, *d*, for looking at elevated objects.

ADJUSTMENTS OF THE EQUATORIAL.

Suppose the latitude of the place and the direction of the meridian to be approximately known, the instrument to show north polar distance, and the hour circle, when the sun is observed to read as an ordinary clock; and let the polar axis be placed nearly in the direction of the poles of the heavens: then the adjustments are—

1. *The elevation of the polar axis to the altitude of the pole.*

2. *The adjustment for collimation in declination, so that the indices of the declination circle point to* 0, *when the telescope points to the pole.*

3. *Adjustment of the polar axis to the plane of the meridian, so that its prolongation may coincide with the poles of the heavens.*

4. *Adjustment for collimation in right ascension, the line of sight being made perpendicular to the declination axis. This is similar to the adjustment for collimation in azimuth of the transit.*

5. *The setting of the declination axis exactly at right angles to the polar axis, if the construction of the instrument allows of this adjustment.*

6. *The adjustment of the right ascension or hour circle to*

read 0^h, when the telescope is in the meridian of the place of observation.

1. *Adjustment of Polar Axis in Altitude.*—Observe any known star, and note the north polar distance as indicated on the declination circle. Turn the instrument half round in right ascension, observe the same star again, and again note the reading of the declination circle. Take the mean of the two readings, correct it for refraction, and the result will be the polar distance indicated by the instrument. Compare this instrumental polar distance with the true polar distance given by the *Nautical Almanack.* If the star observed be above the pole, and the polar distance indicated by the instrument be greater than that given by the *Almanack,* the pole of the instrument is too low, and if the instrumental polar distance be less than the true, the pole of the instrument is too high. If the star observed be below the pole, an error of excess in the polar distance shows that the pole of the instrument is too high, and an error of defect, that it is too low. The position of the axis is to be corrected for elevation by raising or depressing one of its bearings.

2. *Adjustment for Collimation in Declination.*—Take half the difference of the readings of the declination circle in the two observations for index error, move the verniers or reading microscopes through this extent, and the polar distance read off will be the true instrumental polar distance. Several pairs of observation should be made, and the mean of the index errors indicated by them, taken as the real index error.

3. *Adjustment of the Polar Axis to the Plane of the Meridian.*—Turn the instrument round its polar axis, until the telescope is six hours from the meridian either way, and observe the north polar distance of a known star, not *very* near the pole, nor yet near the horizon. Correct for refraction, and compare the result with the true polar distance set down in the *Nautical Almanack.* Suppose the star to be east of the meridian, and the polar distance indicated by the instrument to be too great; then the pole of the instrument inclines to the west, and the upper bearing must be shifted east, or the lower bearing west. Several stars should be observed, and the mean of the corrections indicated be taken as the true amount through which the polar axis is to be moved; but there is no necessity for reversed observations, as in fir adjustment.

The polar axis is now adjusted to the meridian, both in altitude and azimuth.

4. *Adjustment for Collimation in Right Ascension.*—Observe the transit of an equatorial star, note the time, and read the verniers of the hour circle: turn the instrument half way round on the polar axis, and observe again; then the difference of the times, and of the readings of the hour circle, should agree. If they do not, suppose the difference in the clock times to be eight seconds greater than the difference of the readings of the hour circle; then the first transit is four seconds too early, and the second transit is four seconds too late. In the first position, then, move the wires for four seconds, to follow the star in right ascension. If the difference of the clock times be less than the differences of the readings of the hour circle, the first transit is too late, and the second transit too early, and, in the second position, the wires must be moved to follow the star in right ascension.

5. *Adjustment of the Declination Axis exactly at right angles to the Polar Axis.*—This adjustment may be tested either astronomically or mechanically.

Astronomically.—Observe the transit of a star in reversed positions of the polar axis, exactly as for the preceding adjustment, only in this case the star, instead of being on the equator, should be not less than 45° from it. A defect in this adjustment will not produce any error in the time of transit of an equatorial star, the law of the error produced being that it varies as the tangent of the declination. As in the observations for the preceding adjustment, the interval between the two transits is increased or diminished by twice the error in the time of each transit. If, then, the clock interval be eight seconds greater than the difference of the readings of the right ascension, the first transit is four seconds too early, which shows that the telescope points to the east, and that, consequently, the west end of the declination axis is too elevated. At the second transit it is just as much depressed. If the declination of the star be exactly 45°, the amount by which the declination axis is out of adjustment, is equal to the error in the time of transit, converted into angular measure: thus if the transit be four seconds too early, the axis is out of adjustment $4 \times 15''$ or $1'$. the west end being too elevated

If the star have any other declination δ, the amount by which the axis is out of adjustment is $\frac{4}{\tan \delta} \times 15''$.

Before making this adjustment, the previous adjustment is understood to have been perfected, no error of collimation being supposed to exist.

Mechanically.—The declination axis is to be placed exactly horizontal by testing it with a level, as in the cases of the transit instrument and altitude and azimuth instrument; and the reading of the hour circle to be noted. The polar axis is then to be turned half round, the declination axis again placed exactly horizontal, and the reading of the hour circle again taken. If the adjustment be perfect, the difference of the two readings will be exactly twelve hours; but if not, take half the amount by which this difference exceeds or falls short of twelve hours, convert it into angular measure, and call the result e; then the deviation of the axis is given by the equation $\sin d = \tan e \cot l$, in which d represents this deviation, and l the latitude of the place of observation. If the difference of the readings exceed twelve hours, the end of the declination axis, which in the course of the semi-revolution has passed above the polar axis, is too elevated, and *vice versâ*.

6. *Adjustment of the Verniers or Reading Microscopes of the Hour Circle, to read* 0, *when the Telescope is on the Meridian of the Place of Observation.*—If the observer have the means of getting the exact time, let him observe the time of transit of one or more stars not far from the equator, the polar axis of the instrument having been placed and clamped with the verniers of the right ascension or hour circle reading 0. Correct for error of clock. Then the reduced time of transit should be the same as the right ascension of the star, recorded in the *Nautical Almanack;* and if not, the verniers must be shifted, and the instrument again adjusted and clamped, until complete coincidence of the sidereal times of transit with the true right ascension be obtained. If the observer have not the means of getting the time with sufficient accuracy for the application of the preceding test, the declination axis must be placed horizontal by means of a level, and the hour angle indicated on the right ascension circle should then be 0, which the verniers or microscopes should be made to read without altering the position of the instrument.

For all the adjustments, except 8, the observations should be made with the telescope nearly in the meridian. The correction for refraction is, then, at once found from the ordinary tables for refraction, the zenith distance being the difference between the polar distance and the co-latitude for stars above the pole, and the sum of the polar distance and the co-latitude for stars below the pole.

USES OF THE EQUATORIAL.

However well the operations for testing and correcting the adjustments may be performed, the equatorial will not possess the accuracy of the transit and altitude and azimuth instruments. Its uses, however, are two-fold: 1, to observe phenomena, such as the eclipses of Jupiter's satellites, requiring prolonged observation; 2, to determine, in a rapid and simple manner, the place of a body in the heavens, by observations made at any time, this place being previously quite unknown.

METHOD OF OBSERVING WITH THE EQUATORIAL.

For the purpose of prolonged observation of a body, whose right ascension and declination are known, the instrument may be set at once to find it, and the hour circle being then put in connection with the driving-wheel, the clock will move the instrument in right ascension, so as to exactly follow the apparent motion of the heavenly body, caused by the revolution of the earth on its axis.

When used to determine the position of some stranger in the heavens, as a comet, the equatorial should be used merely as a differential instrument. The comet having been observed, and the time noted, let the instrument be clamped both in right ascension and declination, until a known body passes over the field of view, when its time of transit must also be noted and its instrumental declination observed. The observations, both of the comet and of the known body, will be equally effected both by refraction and by the imperfections of the adjustments, and, consequently, the differences, both in the right ascensions and declinations of the two bodies will be accurately determined. If there be no body of nearly the same declination as the comet sufficiently

near in right ascension to pass across the field of view within a short time after the comet, the instrument may be clamped in right ascension only, and stars of both greater and lesser declination by nearly equal amounts may be observed, so that the mean of the corrections for refraction may be nearly the same as the correction for the comet.

INDEX TO VOL. III.

Altitude and azimuth instrument, description of, 142; adjustment of, 144; mode of observing with, 146; use of, 147.
Aneroid barometer, 104.
Artificial horizon, 52.
Astronomical triangle, 147; table of formulæ connecting the parts of, 148.

Barometer, standard, 98; the syphon, 99; the portable or mountain, 99; the wheel, 103; the aneroid, 104; application of, to determination of difference of altitude, 108; meteorological phenomena denoted by, 118.
Bench marks, 31.
Box sextant, 47; parallax of, 49; adjustments of, 51; mode of observing with, 51.

Chain, land, 2; Gunter's, 2; measuring with, 4; examination and correction of, by standard, 5; survey, 9.
Chords, protracting by, 75.
Clinometers, 7.
Collimation, line of, 15; adjustment of, for level and theodolite, 149; in altitude, adjustment for, 63, 145; in azimuth, adjustment for, 63, 136, 145.
Collimator, 151.
Compass, the prismatic, 39; surveying with, 43.
Cross staff, 53.

D'Abbadie's theodolite described, 66.

Edgeworth's stadiometer, 84.
Elliott's improved dumpy level, 22.
Equatorial, the, description of, 153; adjustment of, 154; mode of observing with, 158; uses of, 158.

Formulæ, for true altitude of barometer, *101; for determining height by the barometer, 110;* connecting the parts *of astronomical* triangle, 148.

Gravatt, his adjustment of the level, 18; his level, 20.
Gunter's chain, 2.

Hadley's sextant, 127; adjustments of, 130.
Horizon, artificial, 52.
Hypsometrical instruments, preliminary remarks on, 92.
Hypsometry, barometric, 108; thermometric, 124.

Land chain, 2; surveying with, 9.
Level, the spirit, 10; criterion of a good, 11; the Y, 12; Gravatt's dumpy, 20; Elliott's improved dumpy, 22; the improved dumpy Y, 21; water, 33; reflecting, 34; improved reflecting, 35; draining and mining, 37.
Levelling, remarks on, 26; for section, 28; field-book, 29.
Levelling staves, 24.
Line ranger, the, 54.
Linear and square measure, tables of, 3.

Measuring tape, 9.
Mercurial thermometer, 96.
Meteorological phenomena denoted by barometer, 118.
Microscope, reading, 149.
Mountain barometer, 99.

Northings, southings, eastings, and westings, 75.

Offsetting staff, 8.
Omnimeter, 88.
Optical square, 53.

Parallax from misplacement of spider lines, detected and corrected, 15.
Plotting a section, 32; a survey, 74.
Poles, station, 9.
Portable barometer, 99; transit instrument, 132; altitude and azimuth instrument, 142.
Prismatic compass, the, 39; illustrations of its use, 43.
Protracting by chords, 75; by northings, southings, eastings, and westings, 75.

Ranger, the line, 54.
Ranging rods, 9; lines with the theodolite, 70.
Reading microscope, 149.

Sextant, box, 47; parallax of, 49; adjustments of, 49; mode of observing with, 51; Hadley's, 127; adjustments of, 130.
Spirit level, 10; criteria of a good, 11.
Square, optical, 53; measures, table of, 3.
Stadiometer, Edgeworth's, 84.
Stadium, the, for determining distances in rifle practice, 79.
Staff, levelling, 24; offsetting, 8; cross, 53.
Station poles and ranging rods, 9.
Surveying with chain only, 9; with prismatic compass, 43; with theodolite, 70; with the stadiometer, 86; with the omnimeter, 89.

Tables of linear and square measures, 3; for the reduction of inclined to horizontal distances, 6, 30; of corrections for capillarity, in the heights of the barometric column, 99; of feet in column of atmosphere equivalent in weight to one-tenth of an inch of mercury, at different temperatures, 109; of corrections for temperature to be applied to barometers, 112, 113; of factors and divisors for computation of heights by barometer, 114, 115; of altitudes and corresponding heights of barometer, 116, 117.
Tape, the measuring, 9.
Theodolite, the, 55; the transit, 60; Everest's, 64; Lister's, 66; D'Abbadie's, 66; measuring angles with the, 67; ranging lines with the, 70; traversing with the, 71.
Thermometer, the mercurial, 96.
Thermometric hypsometry, 124.
Transit instrument, 132; adjustments of, 135; method of observing with, 139; use of, 141; theodolite, 60.
Triangle, astronomical, 147; table of formulæ connecting the parts of, 148.

Wheel barometer, the, 103.
Whittley's slide-rule for determination of heights by the barometer, 118.

Y level, the, 12.

THE END.

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